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ADVANCED ORBIT/EPHEMERIS SUBSYSTEM (AOES) TIME TRANSFORMATION REVIEW

Charles M. Randall

Aerospace Corporation
El Segundo, California

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AIR FORCE SYSTEMS COMMAND
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FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract F04701-69-C-0066.

This report, which documents research carried out from 1 September, 1968 through 30 June, 1969, was submitted on 22 August 1969 for review and approval to Col. Arthur A. Banister, Acting Director for Development, Air Force Satellite Control Facility.

Approved

G. A. Paulikas, Director
Space Physics Laboratory

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Satellite Control Directorate

Publication of this report does not constitute Air Force Approval of the report's finding or conclusions. It is published only for the exchange and stimulation of ideas.

ARTHUR W. BANISTER, Col, USAF
Acting Director for Development
AF Satellite Control Facility

ABSTRACT

The time transformations and time dependent inputs for spatial transformations in the Advanced Orbit/Ephemeris Subsystem (AOES) presently being implemented by the Air Force Satellite Control Facility have been reviewed. The principle results are:

1. The relations described in the Milestone 2 documents describing the computer routines include all relations required to satisfy the accuracy design goals of AOES.

2. If future systems require higher accuracy the present time-related transformations will not be adequate. The improvements must involve the following:

   a. Wander of the pole of rotation with respect to the crust of the earth can no longer be ignored.

   b. The empirical relations between earth rotation time scales (UT2, UT1) and atomic time scales (A1, UTC, etc.) must be improved, probably by fitting over shorter periods of time.

   c. Nutation terms of amplitude less than 0.2 arc second must be included.

3. A best set of constants to be employed by the AOES relating UT2 to UTC for the period 1 January 1961 to 30 June 1969 have been calculated. A procedure is suggested for the continuous review of the applicability of these and subsequent constants, with provisions for updating them as required.

4. Values for comparison with computer routine results are presented for many of the quantities under study.

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I. INTRODUCTION

The spsce-time reference frame most convenient for the calculations of satellite ephemerides is not, because of the earth's motion, the most convenient reference frame in which satellite positions may be measured by an observer on the earth. Integration of the equations of motion describing the satellite motion is most conveniently carried out in an inertial coordinate system, while observation is most conveniently carried out in a coordinate system fixed with respect to the surface of the earth.

Both inertial coordinate systems and earth fixed systems are to some extent arbitrary in their definitions of origins and fixed directions. However, once these definitions are established, transformation from the inertial to the earth fixed systems and vice-versa is a straightforward, though often tedious, computational exercise. This transformation requires a knowledge of the earth's motion with accuracy commensurate with the accuracy required from the transformation.

The present report will concentrate attention on the coordinate systems and tranformation schemes employed by the Advanced Orbit/Ephemeris Subsystem (AOES) computer programs presently being implemented by the Air Force Satellite Control Facility. The relations between the time scales employed by it and the computation of time dependent inputs to the spatial transformation procedures of AOES will be reviewed. The basic equations will be presented and the numerical constants appearing in the programs will be evaluated. Where possible, test vslues, against which computer routines may be checked, will be presented.

II. AOES SPACE-TIME COORDINATE SYSTEMS

There are two space-time reference systems used in AOES. The atomic time and inertial system is employed for orbit calculations while the earth fixed system with a precisely defined civil time (UTC) is employed in the rest of the Satellite Control Facility. In this section we discuss the basis for each of the two spatial reference frames used and separately the basis for the two time systems.

A. SPATIAL COORDINATE SYSTEMS

1. INERTIAL COORDINATE SYSTEM

An inertial coordinate system may be defined as one in which Newton's second law of motion (force equals rate of change of momentum) holds. The AOES inertial coordinate system is defined with its origin at the center of mass of the earth and the orientation of its axes defined by the mean equator of the year 1950.0, and the intersection of this equator with the mean ecliptic of 1950, i.e., the mean equinox of 1950.0.

Actually the "inertial" reference frame with origin fixed in the moving earth used by AOES is only an approximation to an inertial reference frame. It will be a satisfactory approximation so long as the acceleration of the satellite due to gravitational attraction by the earth is large compared with the acceleration of the origin of the coordinate system. This requirement is satisfied for earth orbits well beyond synchronous altitudes. This encompasses the uses that will be made of AOES. Therefore we follow the convention of calling a coordinate system with origin fixed at the center of the earth and with its directions fixed in space, an inertial coordinate system.

2. EARTH FIXED COORDINATE SYSTEM

The AOES earth fixed reference frame has its origin at the center of mass of the earth and its orientation specified by the equator and prime meridian of the earth. The AOES actually uses several different coordinate systems which are related to this one by non-time-dependent relations; for example: position determined as azimuth, elevation, and range from a known spot on the surface of the earth. Because we are at present emphasizing only time dependent relations, all of these earth fixed coordinate systems will be regarded as equivalent.

B. TIME SCALES

"Time is not physically tangible; it has no unique physical property that permits its laboratory examination. Time is essentially metaphysical; there is no direct way of measuring it, even in principle. Nonetheless, our lives are ordered by it and, more importantly, our physics is also ordered by it. Therefore time must be measured. The foundations of physical science include the article of faith that a 'uniform' time exists that corresponds identically with the variable called time in dynamics. Even Isaac Newton suspected (Ref. 1, page 8) the impossibility of determining 'uniform' time, and he commented upon the necessity of distinguishing between this construct of faith and the physical measures of time. The failure to reconcile observations with dynamical theories may lead one to amend or discard the laws of dynamics or the means of determination of time, but the faith in a 'uniform' supertime is untouched" (Ref. 2, page 14). In the following we review the specific definitions of the two time scales employed in AOES.

1. ATOMIC TIME, A1

Because the calculation of satellite ephemerides is based on this faith in the existence of a "uniform" supertime, it is convenient to use a practical time scale which agrees as far as is known with the uniform time. The A1 atomic time scale is the one presently available that meets this requirement and has been chosen as the time scale for the inertial space-time coordinate system in AOES. We briefly review the development of this time scale.

The positions of astronomical objects have been, until recently, the basis for the practical determination of uniform time. These positions have been employed because they could be measured quite precisely and because classical dynamics, which was the first branch of physics to develop a precise mathematical formalism, was adequate to predict most of these positions with high precision. Since the chief cause for apparent motion of astronomical objects is the motion of the earth, these time measuring schemes where in fact based on the motion of the earth.

As more precise independent measurements of time became possible by means of quartz oscillators and atomic beam systems, irregularities were discovered in time based on earth motion which could not be quantitatively predicted but could be qualitatively described and were attributed to such things as tidal motions, and seasonal changes in the polar ice masses. It thus became necessary to define the unit of time, the ephemeris second, as a certain fraction of a particular year near the beginning of this century (Refs. 3, 4). The ephemeris time defined in this way can in principle always be found from the reduction of a sufficient number of star position observations but the determination is tedious and can be done only after an event has happened.

The development of the cesium beam clock in the early 1950's introduced a means of keeping time more precise than ephemeris time and with greater convenience. The ephemeris second was measured to be 9 192 631 770 periods of the microwave transition between the hyperfine levels $F = 4$, $m_F = 0$ and $F = 3$, $m_F = 0$ of the $^2S_{1/2}$ ground state of the unperturbed Cs^{133} atom (Ref. 5). A new time scale (A1) has been defined with the above number of oscillations defined as one second and $0^h\ 0^m\ 0^s$ of 1 January 1958 defined as $0^h\ 0^m\ 0^s$ of the atomic time scale. This causes A1 to differ from ephemeris time by 32.15 second.* Up to the present this difference has remained

*The best and most recent value of ET - A1 is 32.15 seconds (Ref. 17). Earlier measurements, however, gave a value of 32.25 seconds. This value is still used in the calculation of many Jet Propulsion Laboratory ephemerides (Ref. 2). Since the only use of ephemeris time in AOES is believed to be obtaining quantities from these JPL ephemerides it is desirable that the same constant be used to relate ET and A1. This requires that ETTOAT, the only entry in CBLK, 'AUBLK2, be 32.25 seconds. If JPL changes the value used in their ephemeris computations then ETTOAT should be changed.

constant indicating that, within the precision of measurements made to date, ephemeris time and atomic time are equivalent. Recognizing this and the convenience with which time can be determined from atomic standards the second was redefined in 1967 as 9 192 631 770 periods of the above mentioned Cs^{133} resonance line. It is this atomic time (A1) which is used in the AOES as the best approximation to uniform time and thus the time variable of integration for determining satellite position.

2. UNIVERSAL TIME

Although atomic time is the most convenient for orbital calculations, a time scale related to the rotation of the earth is employed by the Air Force for observations and communication with other Satellite Control Facility Systems.

The time, using the earth as the clock, may be determined from the observed position of some known point among the stars. More specifically the angle along the celestial equator from the great circle through the observer's zenith west to the great circle through the known point is used. These angles, usually measured in units of hours, are called hour angles. The local time, XT, on the x scale, where x is the accepted reference point in the sky, is then the hour angle of reference point; $XT = ha_{(x)}$. By this definition only observers at the same longitude will have the same time, which is inconvenient. Therefore a single meridian is defined by convention as the time keeping meridian. Then the local time, $XT_{\ell oc} = XT + \text{longitude}$, where XT is the time at the prime meridian and longitude is measured increasing to the west from the prime meridian.

Two reference points and their related time scales are required in AOES. One point is the equinox of date and the associated time scale is called sidereal time (ST). This time (or angle) is required to relate the "inertial" coordinate system to the earth fixed one. The second reference point, which defines the universal time scale, the basis for civil time keeping, is always very nearly directly opposite the sun. Because of the earth's motion about

the sun, the second reference point is in constant motion with respect to the first. A relation between them is required. By definition:

$$ST = ha_{(equinox)}$$

The angle from the equinox to the universal time point is defined (Ref. 6) to be 12 hours + R_u where

$$R_u = 18^h\ 38^m\ 45^s.836 + 8640184^s.542\ T + 0^s.0929T^2$$

and T is the number of Julian centuries of 36525 days which have elapsed since 12^h UT on 0 January 1900.

$$UT = ha_u = ha_{eq} - R_u - 12^h$$

$$UT = ST - R_u - 12^h \tag{1}$$

UT is thus determined by means of Eq. 1 from sidereal time obtained by observing the zenith transit of stars whose position with respect to the equinox is accurately known.

When this time scale is compared with an independent precise time scale, such as atomic time, UT is observed to have a varying difference from the atomic time. There appears to be 1) changes which depend on the observer's location and result from the wandering of the earth's pole of rotation with respect to the crust of the earth; 2) changes which are seasonal; and 3) gradual slowing down of the earth rotation rate. None of these can be completely predicted on a theoretical basis and are the subject of study due

to their intrinsic interest (Refs. 7, 8). Three time scales in use reflect these various differences: UT0 is the time scale which results from applying Eq. 1 to measured star positions. UT1 is the result of correcting UT0 for polar motion, UT2 is the result of correcting UT1 for seasonal variations. The only effect left in UT2, then is the gradual slowing down of the earth.

The UTC time scale is designed to provide a convenient time scale with the stability of atomic clocks and still be a close approximation to UT2. Because of the measurements and corrections required, UT2 can be determined only long after an event, and is therefore inconvenient for many purposes. The ratio of the length of the UTC second to the A1 second length is held constant at a value such that the UTC second is approximately the same length as the UT2 second. The value of this ratio is decided upon and announced in advance by an international bureau on the basis of recent trends in UT2. When the difference between UT2 and UTC becomes larger than about 100 milliseconds, a step is put in UTC to bring the two closer together. UTC is the time scale used by AOES for communication with other Satellite Control Facility systems.

It is important to recognize that UTC and A1 have a mathematically defined relation between them. Given one the other can always be found to within the accuracy of constants in a formula. Similarly UT0 and sidereal time have a mathematically defined relationship. On the other hand the relations between UT0 UT1, UT2, and UTC are basically empirical, though they can be estimated with fair accuracy on the basis of past experience.

III. COORDINATE SYSTEM TRANSFORMATIONS

Relating the position of a object as expressed in inertial coordinates to the position in earth fixed coordinates requires only a knowledge of the orientation of one coordinate system with respect to the other at any given time. Since the largest part of the change in orientation is due to the earth's motion, which is for the most part quite predictable, the most logical way to obtain the required transformation would seem to be to compute the relative orientation at any specific time, to apply this to relate the position vector in the two coordinate systems, and finally to apply small corrections, predicted as best as possible by statistical means on the basis of recent empirical data on the motion of the earth.

This is generally the procedure actually followed in AOES although the detailed way in which the corrections are made reflects the traditional coordinate systems of the astronomer. The transformation is broken into several parts, some of which (precession and nutation) are introduced as changes in the inertial coordinate system, others (rotation of earth about its axis, seasonal and random variations in the rotation rate) are introduced via the time, and some, such as polar wander are applied directly. In addition to the spatial transformations there is a time transformation between A1 and UTC.

The steps in the transformations between the inertial system of AOES and the earth fixed systems of AOES are indicated schematically in Fig. 1. The mathematical formulation of the transformations is described in detail in Ref. 9 and will not be repeated in its entirety here. The purpose of the present report is 1) to review the inputs to these transformations which are time dependent, and 2) to review the transformations between the A1 time scale used in the inertial system and the UTC time scale used in communicating with the world outside the AOES. These are the operations taking place within the broken line in Fig. 1.

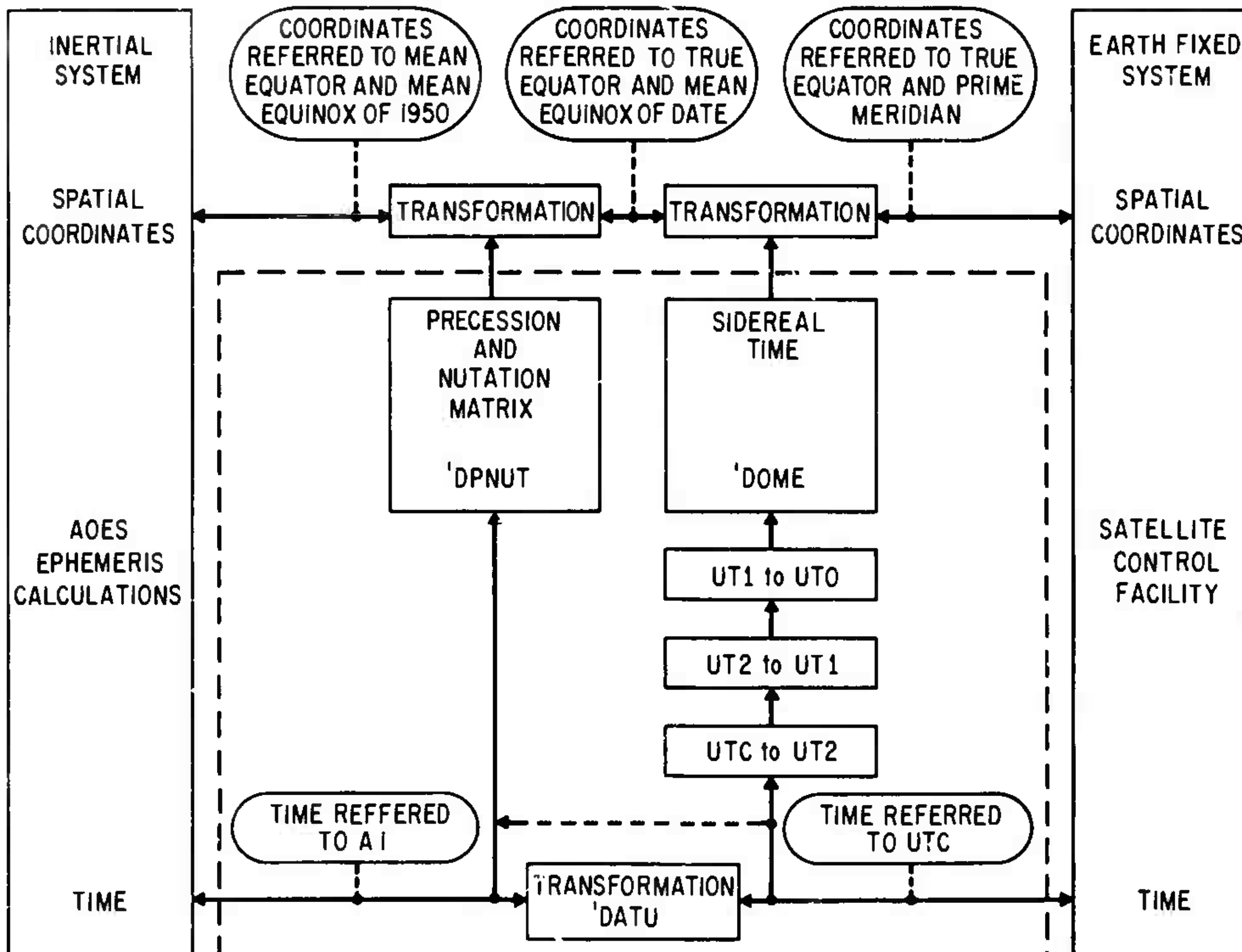

Figure 1. Schematic Representation of Space-Time Reference Systems in AOES Emphasizing Transformations Between Them which are Time Dependent. Those Computations Referred to within the Broken Line are the Detailed Concern of this Report.

The AOES computer routines which perform these calculations are: 'DATU (Atomic to Universal Time), 'DOME (Sidereal Time), and 'DPNUT (Precession Nutation Matrix). A fourth routine, 'DATIME, performs housekeeping functions such as converting the time between two dates into minutes. Since it introduces no new time scales or transformations, it will not be reviewed here. The physical constants required for 'DATU and 'DOME are found in the system data base as a constant block 'AUBLK. In the following sections numerical values of all the constants in 'AUBLK will be calculated. This information is summarized in Appendix D, which, for every entry in 'AUBLK, either lists the value calculated in this report or refers to the tabulation of that value elsewhere in the report. The constants required for 'DPNUT are part of the code for that routine.

The accuracy of the tranformation should meet and exceed the design goals of AOES. In terms of a nominal 90 minute orbit "nothing in the computer program shall preclude the attainment of these accuracies:" 50 ft cross track, 200 ft in track and 100 ft radial distance (Ref. 10). In angular measure the 50 ft requirement for a satellite at 185 miles with a 90 minute period requires an angular accuracy of 0.47 arc sec or 30 milliseconds time.

A. TIME DEPENDENT SPATIAL TRANSFORMATION INPUTS

Referring to Fig. 1, there are two time dependent inputs to the spatial transformations. These are the sidereal time (computed by 'DOME) and the precession-nutation matrix (computed by 'DPNUT).

1. SIDEREAL ANGLE

The most important quantity required for transformation between the earth fixed and the AOES inertial system is the angle between the prime meridian of the earth fixed system and the meridian through the mean equinox of date. This, however, is just the hour angle of the equinox, or the sidereal time. From Eq. 1 of the earlier discussion of time bases, this is:

$$\theta = ST = UT + R_u + 12^h$$

Converting to degrees and AOES base time, this becomes:

$$\theta = UT + 100^{\circ}.0755416 + 0^{\circ}.9856473458\ d + 2.90 \times 10^{-13} d^2 \tag{2}$$

where d is the universal time in days since AOES reference time.* Some checks of the computer routine for sidereal angle have been conducted (Ref. 11). Values for additional checks may be obtained from the ephemeris (Ref. 12) for any year under the heading Mean Sidereal Time.

2. PRECESSION AND NUTATION

Because of the gravitational attraction of other bodies in the solar system the rotation axis of the earth does not remain fixed in space, but slowly, over a period of about 26000 years, describes a circle of about 23.5° radius. Furthermore the combined effects of the planets serve to slowly change the plane of the earth's orbit (the ecliptic). The combined motion is known as general precession of the mean pole. In addition, there are various shorter period motions of the true pole about the mean pole position described as nutation.

We are principally concerned here that the angular arguments used to compute the nutation and precession matrices are correct. In order to be specific about the arguments, however, it is necessary to give the way in which they are used, which means specifying the transformation matrices. Assume we wish to transform a vector specified by its position with respect to the mean equinox and true equator of date, (center of Fig. 1) to a position vector in the AOES inertial reference frame which is referred to the mean equinox and equator of 1950 (left side of Fig. 1). Transformation from

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*To avoid very large numbers in some calculations all times in AOES are, by convention, measured from a reference time of 0^h 1 January 1950.

The first two constants in Eq. 2, expressed as fractions of a revolution, are THK1 and THK2 in constant block 'AUBLK in the AOES data base. For some purposes the rate of change of sidereal time with respect to UT2 is needed. This may be obtained by differentiating the above equation. The result is THDK1 in 'AUBLK. In all cases the quadratic term is ignored.

mean equinox and true equator of date to mean equinox and mean equator of date is accomplished by the nutation matrix N. Transformation from mean equinox and equator of date to mean equinox and equator of 1950.0 is then accomplished by the precession matrix, P.

$$\vec{r}_o = PN\,\vec{r}$$

We look at each matrix in some detail now.

a. Nutation

Nutation is specified by two angles: $\Delta\psi$, the angular separation measured along the ecliptic between the mean and true equinoxes (K and K' in Fig. 2), and $\Delta\varepsilon$, the difference in angle between the equatorial planes and the ecliptic plane for the true equator ε_1 and the mean equator ε_2. The transformation is first $\Delta\psi \cos \varepsilon$ about z, then ε_1 about the new x axis, then $\Delta\psi$ about the latest z axis, and finally $(-\varepsilon_2)$ about the latest x axis. Combining all these operations into one matrix, using the small angle approximation and keeping terms only to the first order in $\Delta\varepsilon$ and $\Delta\psi$, the resulting nutation matrix N is

$$N = \begin{pmatrix} 1 & 0 & \Delta\psi \sin \varepsilon \\ 0 & 1 & \Delta\varepsilon \\ -\Delta\psi \sin \varepsilon & -\Delta\varepsilon & 1 \end{pmatrix}$$

The arguments required are $\Delta\psi$ and $\Delta\varepsilon$ which are given by trigonometric series, the constants of which have been determined partially theoretically and partially empirically.

$$\Delta\psi = \sum_{i=1}^{N} a_i\,(t)\,\sin\,[\alpha_i(t)]$$

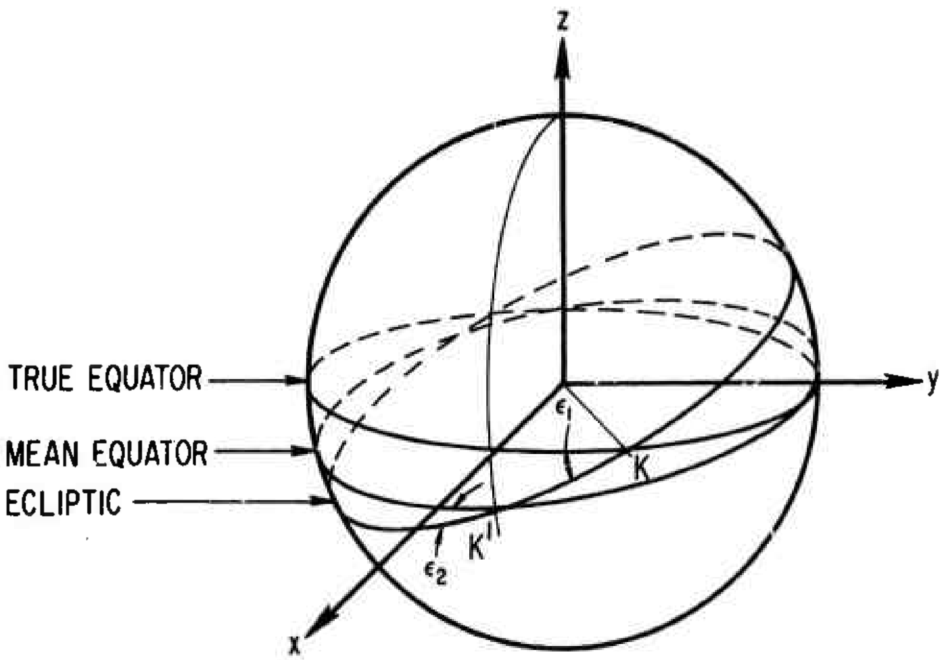

Figure 2. Geometry Relating the True Equator and Mean Equator of Date from which the Nutation Matrix may be Computed. The Angle KK' is the Nutation in Longitude, $\Delta\psi$. The Difference Between the Inclination of the True Equator to the Ecliptic (ε_1) and the Mean Equator to the Ecliptic (ε_2) is the Nutation in Obliquity, $\Delta\varepsilon$.

$$\Delta\varepsilon = \sum_{i=1}^{N} b_i\ (t)\ \cos\ [\alpha_i(t)] \tag{13}$$

where t is time. The $\alpha_i = \sum_{j=1}^{4} \beta_{ij}\ F_j(t)$, are various linear combinations of $F_j(t)$ which are in turn polynomials in t. Listed in the <u>Explanatory Notes to Ephemeris</u> (Ref. 6) are 69 terms with $a_i \geq 0.0002$ arc sec and 40 with $b_i \geq 0.0002$ arc sec. The 0.47 arc sec accuracy required by AOES suggests that not nearly all of these terms are required. Table 1a lists the coefficients of the functions which have either a_i or b_i greater than 0.1 arc sec. Table 1b lists the coefficients in the F(t) polynomials. The time arguments (d_n and T_n) to be used with the coefficients of Table 1 are measured from the beginning of the present Julian Century while the time arguments in AOES are measured in days, d, since AOES base time. The relations between these quantities are: $d_n = d + 18262.5$ and $T_n = d_n/36525$.

Computer calculations may be checked by comparison with the values listed in Table 2. For 10 day intervals during 1968, the nutation in longitude ($\Delta\psi$) and nutation in obliquity ($\Delta\varepsilon$) are listed as obtained both from the limited series of Table 1 and from the full series as tablulated in the 1968 ephemeris (Ref. 12). The nontrivial matrix elements, $N_{13} = \Delta\psi \sin \varepsilon$, and $N_{23} = \Delta\varepsilon$ corresponding to the limited series calculation are also listed. The maximum difference between the ephemeris and the calculated values is 0.171 arc sec. The average difference without regard to sign, is 0.059 arc sec, well within the accuracy requirement of AOES.*

*'DPNUT does not include the i = 4 term from Table 1a. When this term is not included, the same comparison over 1968 gives a maximum difference of 0.261 arc sec and an average without regard to sign of 0.083 arc sec. The maximum error is within a factor of two of the AOES design limit.

The Data Dynamics Inc. literature on 'DPNUT chose to test the nutation matrix on 1.^{d}0 January 1980. The values calculated on the basis of Table 1 for this date are $\Delta\psi = -7''.958$, $N_{13} = -1.5350 \times 10^{-5}$, and $N_{23} = -4.2547 \times 10^{-5}$. If i = 4 term of Table 1a is not included, we then calculate $\Delta\psi = 7''.952$, $\Delta\varepsilon = -8''.776$. $N_{13} = -1.5338 \times 10^{-5}$, and $N_{23} = -4.2547 \times 10^{-5}$. These latter values are in good agreement with the test number published in the 8/15/07 Milestone 4, revision B, of 'DPNUT.

Table 1. Coefficients and Functions for Nutation Calculations

a. Coefficients of nutation trignometric series.

Index, i	β_{i1}	β_{i2}	β_{i3}	β_{i4}	a_i ($\Delta\psi$ longitude) (arc sec)	b_i ($\Delta\varepsilon$ obliquity) (arc sec)
1	0	0	0	1	$-17.2327 - 0.01737\ T_n$	$+9.21 + 0.00091\ T_n$
2	0	0	0	2	$+0.2088 + 0.00002\ T_n$	$-0.0904 + 0.00004\ T_n$
3	0	2	-2	2	$-1.2729 - 0.00013\ T_n$	$+0.5522 - 0.00029\ T_n$
4	1	0	0	0	$+0.1261 - 0.00031\ T_n$	
5	0	2	0	2	$+0.2037 - 0.00002\ T_n$	$+0.0884 - 0.00005\ T_n$

b. Coefficients of nutation polynomials

$$F_j = f_{j0} + f_{j1}d_n + f_{j2}d_n^2 + f_{j3}d_n^3$$

Index, j	f_{j0} (deg)	f_{j1} (deg)	f_{j2} (deg)	f_{j3} (deg)
1	358.475833	0.9856002669	-1.12×10^{-13}	-6.8×10^{-20}
2	11.250889	13.2293504490	-2.407×10^{-12}	-7.0×10^{-21}
3	350.737486	12.1907491914	-1.076×10^{-12}	3.9×10^{-20}
4	259.183275	-0.0529539222	1.557×10^{-12}	4.6×10^{-20}

Table 2. Nutation Matrix Values for 1968

Julian Day	Nutation in Longitude $\Delta\psi$ (arc sec) Calculated	Nutation in Longitude $\Delta\psi$ (arc sec) Ephemeris (Ref. 13)	Nutation in Obliquity $\Delta\varepsilon$ (arc sec) Calculated	Nutation in Obliquity $\Delta\varepsilon$ (arc sec) Ephemeris (Ref. 13)	Off-Axis Matrix Elements (Units of 10^{-5}) $N_{1,3}$	Off-Axis Matrix Elements (Units of 10^{-5}) $N_{2,3}$
2439855.5	-6.477	-6.401	7.736	7.708	-1.2494	3.7507
65.6	-6.149	-6.132	7.946	7.949	-1.1861	3.8521
75.5	-5.457	-5.428	8.203	8.224	-1.0527	3.9768
85.5	-4.949	-4.822	8.299	8.320	-0.9546	4.0236
95.5	-5.027	-5.089	8.457	8.472	-0.9697	4.1001
2439905.5	-5.098	-5.150	8.791	8.832	-0.9835	4.2622
15.5	-4.901	-4.891	9.008	9.046	-0.9454	4.3674
25.5	-5.058	-5.209	9.014	8.996	-0.9757	4.3699
35.5	-5.630	-5.683	9.085	9.064	-1.0859	4.4044
45.5	-5.890	-5.948	9.227	9.223	-1.1361	4.4734
2439955.5	-5.839	-5.927	9.150	9.107	-1.1264	4.4359
65.5	-6.096	-5.992	8.918	8.874	-1.1760	4.3233
75.5	-6.423	-6.444	8.826	8.797	-1.2390	4.2789
85.5	-6.178	-6.182	8.776	8.775	-1.1918	4.2549
95.5	-5.696	-5.525	8.538	8.543	-1.0988	4.1392
2440005.5	-5.532	-5.542	8.307	8.292	-1.0671	4.0272
15.5	-5.249	-5.292	8.316	8.345	-1.0125	4.0316
25.5	-4.450	-4.362	8.355	8.389	-0.8584	4.0506
35.5	-3.745	-3.793	8.267	8.261	-0.7225	4.0079
45.5	-3.496	-3.542	8.311	8.303	-0.6744	4.0294
2440055.5	-3.117	-3.119	8.585	8.592	-0.6013	4.1619
65.5	-2.478	-2.525	8.788	8.782	-0.4780	4.2604
75.5	-2.271	-2.213	8.861	8.833	-0.4381	4.2958
85.5	-2.522	-2.533	9.075	9.046	-0.4865	4.3996
95.5	-2.546	-2.567	9.383	9.383	-0.4912	4.5490
2440105.5	-2.452	-2.329	9.478	9.477	-0.4730	4.5953
15.5	-2.842	-2.835	9.437	9.407	-0.5483	4.5754
25.5	-3.391	-3.378	9.520	9.516	-0.6540	4.6153
35.5	-3.464	-3.375	9.575	9.601	-0.6683	4.6419
45.5	-3.426	-3.436	9.376	9.375	-0.6608	4.5458
2440155.5	-3.723	-3.649	9.142	9.142	-0.7183	4.4323
65.6	-3.811	-3.804	9.078	9.103	-0.7352	4.4013
75.5	-3.309	-3.370	8.961	8.989	-0.6383	4.3446
85.5	-2.827	-2.729	8.681	8.701	-0.5454	4.2086
95.5	-2.627	-2.667	8.531	8.529	-0.5067	4.1362
2440205.5	-2.088	-2.196	8.598	8.629	-0.4028	4.1686
15.5	-1.173	-1.092	8.599	8.624	-0.2263	4.1689
25.5	-0.609		8.530		-0.1175	4.1354

b. Precession

The precession is described by the three angles shown in Fig. 3. $\alpha = 90° - \xi_o$ is the right ascension of the ascending node (η) of the equator of epoch t on the equator of t_0 reckoned from the equinox of t_0. $\beta = 90° + z$ is the right ascension of the node (η) reckoned from the equinox of t on the equator of t and θ is the inclination of the equator of t to the equator of t_0. To transform X, Y, Z components of one system to X_0, Y_0, and Z_0 of the other requires first a rotation + β about Z, $-\theta$ about the new X, and finally $-\alpha$ about the latest Z axis. The P matrix elements then result from straightforward trigonometry.

$$P_{11} = \cos \zeta_o \cos \theta \cos Z - \sin \zeta_o \sin Z$$

$$P_{21} = -\sin \zeta_o \cos \theta \cos Z - \cos \zeta_o \sin Z$$

$$P_{31} = -\sin \theta \cos Z$$

$$P_{12} = \cos \zeta_o \cos \theta \sin Z + \sin \zeta_o \cos Z$$

$$P_{22} = -\sin \zeta_o \cos \theta \sin Z + \cos \zeta_o \cos Z$$

$$P_{32} = -\sin \theta \sin Z$$

$$P_{13} = \cos \zeta_o \sin \theta$$

$$P_{23} = - \sin \zeta_o \sin \theta$$

$$P_{33} = \cos \theta$$

The angles are given by (Ref. 6):

$$\zeta_o = (2304''\!.250 + 1''\!.396\ T_{0p})\ T_p + 0''\!.302 T_p^2 + 0''\!.018\ T_p^3$$

$$z = \zeta_o + 0''\!.791\ T_p^2$$

$$\theta = (2004''\!.682 - 0''\!.853\ T_{0p})\ T_p - 0''\!.426\ T_p^2 - 0''\!.042\ T_p^3$$

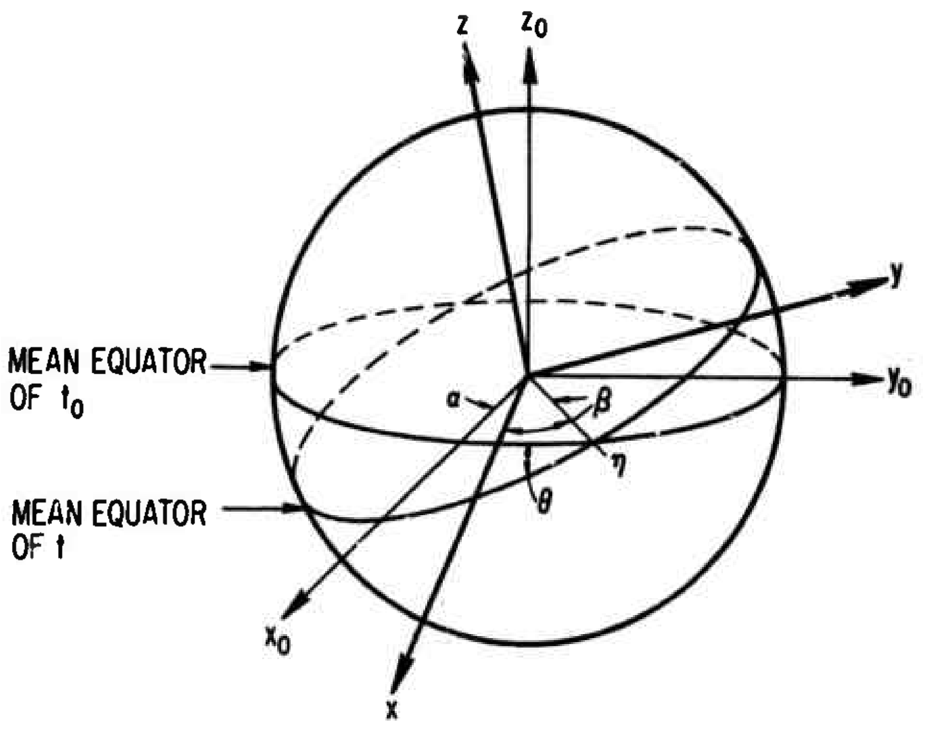

Figure 3. Geometry Relating the Mean Equator of t_o to the Mean Equator of Time t, from which the Precession Matrix may be Computed.

T_p is the time interval between the two epochs measured in tropical centuries of 36524.22 days. T_{0p} is the time since Besselian year 1900.0, also measured in tropical centuries. Changing to AOES base time, which is 0.077 day into Bessellian year 1950, $T_{0p} = 0.5$ and $T_p = (0.077 + d)/36524.22$, where d is the number of days since AOES reference time. The equations then become:

$$\zeta_o = 2304''.948\ T_p + 0''.302\ T_p^2 + 0''.018\ T_p^3$$

$$z = \zeta_o + 0''.791\ T_p^2$$

$$\theta = 2004''.2555\ T_p - 0''.426\ T_p^2 - 0''.042\ T_p^3$$

The results of calculating the angles and the matrix elements for a few selected times are tabulated in Table 3. Also tabulated are results for approximately the same times taken from Tables 2.1 and 2.2 of the Explanatory Notes to the Ephemeris (Ref. 6). The differences in the angles are due to the calculation being made for $0^h.0$ on January 1 while the ephemeris tables were computed for the beginning of the Besselian Year.*

B. TIME TRANSFORMATIONS

The time transformations required are between UTC, used in earth fixed system, and A1 used in the inertial system. Since sidereal time is directly proportional to UT0, the relation between UT0 and A1 or UTC must also be accurately known. Universal time is required to calculate the precession-nutation matrix but since this is a small correction the differences between UTC and A1 are insiginificant. This section reviews these transformations between time scales.

*The times for which values are preseuted in Table 3 are the times used for testing the P matrix in 'DPNUT. The values in Table 3 for the off axis matrix elements differ slightly but significantly from the values published in 'DPNUT, Milestone 4, Revision B, 8/15/67. It is suspected this is due to roundoff error in the Milestone 4 values but this is not definitely known.

Table 3. Calculated Precession Matrix Values

	$0^h\!.0$ 1 Jan 1960		$0^h\!.0$ 1 Jan 1970		$0^h\!.0$ 1 Jan 1980	
	Calculation	Ephemerus (Ref. 6)	Calculation	Ephemerie (Ref. 6)	Calculation	Ephemeris (Ref. 6)
ξ_o (sec)	15.3651	15.367	30.7344	30.733	46.1000	46.101
ζ (sec)	15.3656	15.367	30.7365	30.736	46.1047	46.106
σ (sec)	13.3601	13.361	26.7231	26.722	40.0818	40.082
P_{11}	.99999703	.99999702	.99998812	.99998807	.99997327	.99997324
$P_{12} = -P_{21}$	.00223479	.00223479	.00447028	.00447028	.00670526	.00670526
$P_{13} = P_{31}$	.00097153	.00097157	.00194335	.00194335	.00291481	.00291480
P_{22}	.99999750	.99999749	.99999001	.99998997	.99997752	.99997749
$P_{23} = P_{32}$	-.00000109	-.00000109	-.00000434	-.00000436	.00000977	.00000979
P_{33}	.99999953	.99999953	.99999811	.99999810	.99999575	.99999574

1. A1 TO UTC

The UTC time scale is related to the A1 scale as follows:

$$A1 = UTC + a_i - s_i \, (UTC - UTC_i)$$

The s_i are frequency offsets decided in advance and announced by an international bureau to keep the rate of change of UTC with respect to A1 about equal to the average rate of change of UT2 with respect to A1. The s_i are changed only on the beginning of a year. The a_i are also decided upon and announced in advance by the same international bureau, when UTC and UT2 differ by more than about 0.1 sec. The a_i may be changed at the beginning of any month.

Values of the frequency shifts, s_i and offsets, a_i, have been calculated for all the changes which have taken place in UTC between 1 January 1961 and 30 June 1969. These are presented in the first three columns of Table 4. The values of UTC_i appearing in the first column are given in units of days since AOES base time. (The 1 August 1963 entry is an exception in that no defined change in UTC took place at this time. This entry was introduced to reduce the maximum difference between UTC and UT2 (See Appendix C).

During the early part of this time period the clocks used could not be held at precisely the nominal announced frequency offset, s_i. This is reflected in Table 4 by the s_i which do not have a simple value. The values for s_i which are specified to 3 decimal places are the results of least squares fitting to the time scale established by the National Bureau of Standard Radio Station (WWV) broadcasts. The UTC values calculated from the constants differ in all cases by less than one millisecond from the UTC time scale established by WWV. The advances in frequency control at U.S. Naval Observatory (USNO) and within the Satellite Control Facility should make corrections to the nominal offset, s_i, unnecessary in the future.

Table 4. AUTAB from Least Squares Fit to US Naval Observatory Data

Notation in this report	UTC_i	s_i	a_i	c_i	d_i	
AUTAB item	UTCDIS	FRQSHF	UCTAA	UCTU2C	UCTU2D	Maximum
Dates	(days)	(units of 10^{-10})	(units of 10^{-2} min)	(units of 10^{-4} min)	(units of 10^{-10})	$\lvert UT2_{calc} - UT2_{USNO} \rvert$ (msec)
1 Jan 61 to 1 Aug 61	4018	-148.958	2.4353	2.8909	32.505	10.0
1 Aug 61 to 1 Jan 62	4230	-150.0	2.8067	2.3291	6.5518	2.0
1 Jan 62 to 1 Aug 63	4383	-129.778	3.1370	5.3254	-21.245	16.0
1 Aug 63 to 1 Nov 63	4960	-129.485	4.2157	-14.203	-85.571	0.3
1 Nov 63 to 1 Jan 64	5052	-130.0	4.5538	-8.9828	-80.324	0.6
1 Jan 64 to 1 Apr 64	5113	-150.0	4.6677	-16.084	-64.699	1.0
1 Apr 64 to 1 Sep 64	5204	-149.768	5.0310	-7.4724	-68.523	3.0
1 Sep 64 to 1 Jan 65	5357	-150.0	5.5288	-6.4912	-85.260	7.0
1 Jan 65 to 1 Mar 65	5479	-150.0	5.9593	-4.7161	-72.321	0.4
1 Mar 65 to 1 Jul 65	5538	-150.0	6.2533	5.3646	-95.223	5.0
1 Jul 65 to 1 Sep 65	5660	-150.0	6.6835	4.8843	-118.35	0.6
1 Sep 65 to 1 Jan 66	5722	-150.0	6.9840	10.053	-128.91	8.0
1 Jan 66 to 1 Feb 68	5844	-300.0	7.2476	-8.9162	20.398	22.0
1 Feb 68 to 9 Jul 69	6605	-300.0	10.3665	-1.1220	9.1113	18.0

2. A1 TO UTO

a. Timing Polynomials, A1 to UT1

As discussed under time scales, the relationship between atomic based time scales, such as UTC or A1, and earth motion time scales such as UTO is, when considered at their highest accuracy, a relation which is known precisely only after an event has occurred. A most straightforward way to obtain UTO from A1 would be a power series fit to obtain UT1, then the station peculiar correction to get UTO. The constants in the formula would be changed whenever the fit became unsatisfactory. This is the approach taken by the Jet Propulsion Laboratory (Refs. 14, 15) and the coefficients of their timing polynomials are readily available (Table 3, Ref. 2). From these coefficients "the value of A1-UT1 is known to ±0.005 sec. after the fact and to 0.0002 sec/day^2 additional when predicting ahead." To accomplish this accuracy requires 41 different sets of polynomials to cover the period from 1 January 1961 through June 1969.

b. Successive Corrections, UTC to UT2

Another approach is to take advantage of AOES's use of UTC, which is already a first approximation to UT2 and apply in reverse the corrections used to get UTC from UT1. This is the approach followed by AOES. A linear relation between UTC and UT2 is assumed.

$$UT2 = UTC + C_1 + d_1 \ (UTC - UTC_1)$$

As a programming convenience the same UTC_1 used for the UTC to A1 conversion are used here. Tabulated in Table 4 are the constants resulting from a least squares fit of this formula to the USNO determined UT2 scale. (Ref. 16). The maximum values of |UT2(calculated) - UT2(USNO)| are also tabulated in Table 4--the absolute difference between the UT2 calculated from the constants and the UT2 established by the US Naval Observatory.

The largest errors are around 20 msec, some four times larger than the JPL timing polynomials errors, but only 14 different sets of constants are required to cover the 1961 to 1969 period compared with the 41 required for JPL polynomial. The 22 msec is still well within the 30 msec accuracy requirement of AOES. In Appendix A, all of the USNO time data employed are tabulated along with the calculated values of UTC and UT2 obtained from the constants of Table 4 for each input time.

c. UT2 to UT1

After determining UT2, the seasonal correction, S, must be applied to obtain UT1. UT1 = UT2 - S. The assumed form of S is:

$$S = u_1 \sin(2\pi t) + u_2 \cos(2\pi t) + u_3 \sin(4\pi t) + u_4 \cos(4\pi t)$$

where t is the fraction of a Julian year of 365.25 days since 1 January of the year. The u_i are chosen for an entire year.* Values found by a least squares fit to the USNO data (Ref. 16) are listed in Table 5. The complete USNO data and the fit for all input values is shown in Appendix B. For all years except 1962 the errors are less tban the 1 msec accuracy with which the USNO values are stated.

Table 5. Seasonal Time Variation Coefficients

Year	u_1 (sec)	u_2 (sec)	u_3 (sec)	u_4 (sec)
1961	0.0221	-0.0169	-0.0069	0.0059
1962	0.0210	-0.0135	-0.0074	0.0067
1963-68	0.0220	-0.0120	-0.0059	0.0070

*The u_i are tbe U1K1, U1K2, UJK3, U1K4 of the constant block 'AUBLK in the AOES data base.

d. UT1 to UT0

The correction from UT1 to UT0 is really another coordinate change which should be applied to relate earth fixed coordinates referred to a point on the earth to earth fixed coordinates referred to the pole of rotation. If $\vec{r}$ is a vector determined with respect to a system of coordinates defined by the mean pole of 1903 and $\vec{r}\,'$ is a vector determined with respect to a system of coordinates defined by the current pole of rotation then

$$\vec{r}\,' = R\,\vec{r}$$

where

$$R = \begin{pmatrix} 1 & 0 & x \\ 0 & 1 & y \\ -x & -y & 1 \end{pmatrix}$$

And x and y are shifts from the mean pole in radian measure. If λ is the longitude and ϕ the latitude, this same change can be represented as a change of latitude, $\Delta\phi$ and longitude, $\Delta\lambda$.

$$\Delta\lambda = \lambda' - \lambda = \tan\phi(x \sin\lambda + y \cos\lambda)$$

$$\Delta\phi = \phi' - \phi = x \cos\lambda - y \sin\lambda$$

The values of x and y are presented as a polar plot for the 1962 to 1968 time period in Fig. 4 (Ref. 2). It will be noted that over a period of 6 months the values have changed by as much as 0.5 arc sec. This is approximately equal to the design goal of AOES and is not corrected for in AOES tranformations since the correction is station peculiar.

e. Accuracy

The largeat aingle error source is the polar motion which is not corrected for and may amount to ±.020 sec time. The next largest source of error ia the converaion from UTC to UT2 which may at times be in error nearly as much. The other corrections are never in error by more than 0.1 of these amounts. If these two sources of error were independent and random (neither of which is probably true) then one might expect the total error to be $(2)^{1/2}$ times the error from either of the two sources of equal magnitude or about ± 0.030 sec time--just about the AOES design goal.

Thus the present AOES transformation achieves the design accuracy goals. Improvement in accuracy of other parts of the system beyond the preaent goals is not useful unless the transformations are also improved. For greater accuracy the relation between A1 (or UTC) and UT2 must be improved, perhaps by uaing something like the JPL timing polynominals, and the polar motion must be included.

3. PARAMETER UPDATE

Meat of the parameters occurring in the various time transformation equations are not varying, and except to review them occasionally to assure that the best currently available values are in use, they do not need to be changed. Exceptions to this are the constants relating A1 to UTC to UT1. Theae constants must be updated to reflect the most recent available information. A convenient source of this current information is the weekly bulletin of the US Naval Observatory, "Preliminary Times and Coordinates of the Pole, Series 7", which gives information on UTC, UT2, UT1, UT0 and should it be useful sometime in the future x, and y coordinates of the pole. Appendix C outlines a possible aystematic way to incorporate this data as it becomea available, while at the same time making a minimum number of changes in the computer data base.

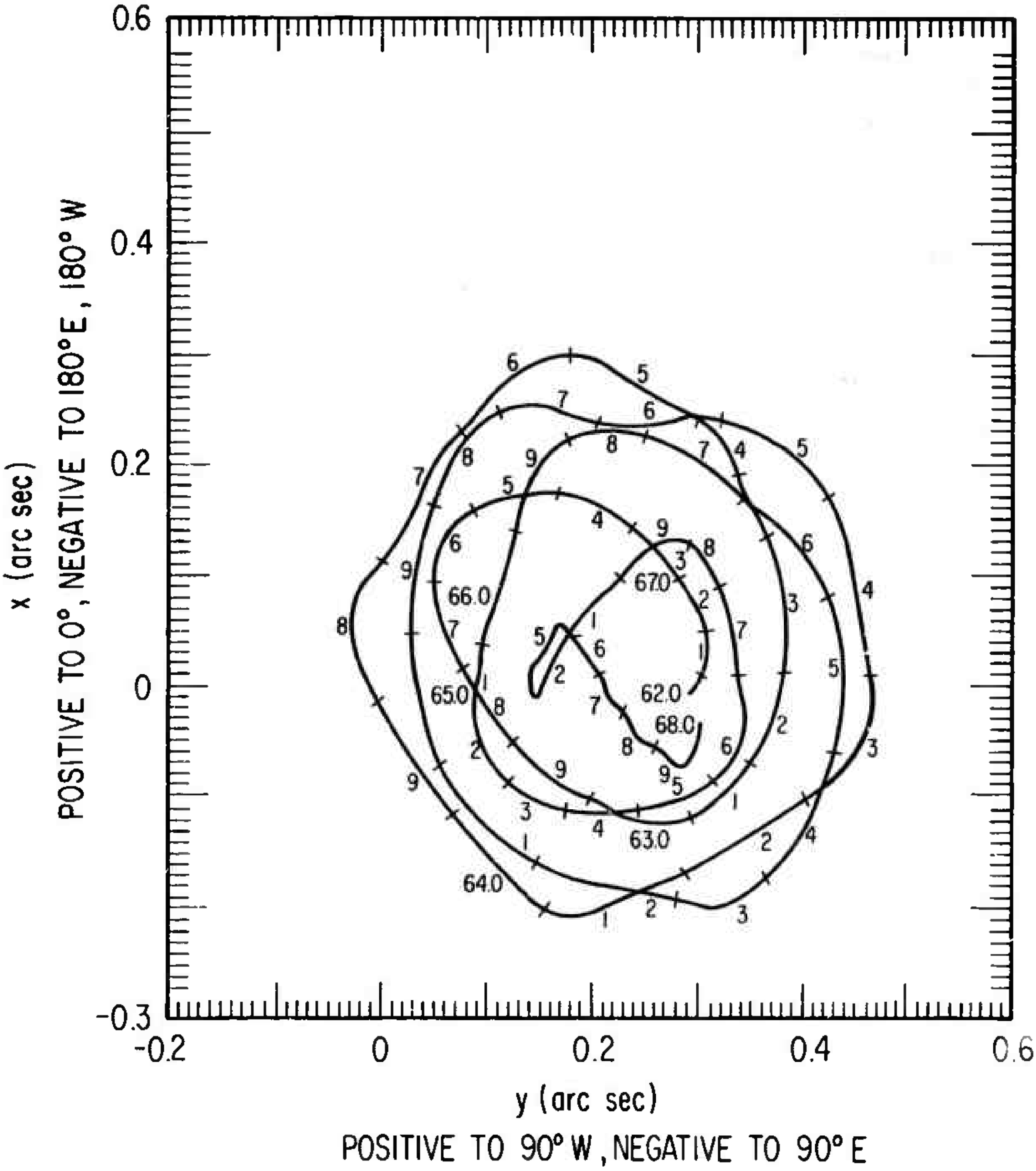

Figure 4. Polar Orbit Plot of the Coordinates of the Pole of Rotation of the Earth for the Period 1962 to 1968 (Ref. 2).

REFERENCES

1. I. Newton, Mathematical Principles of Natural Philosophy, University of California Press, Berkeley, 1962.

2. W. G. Melbourne, J. D. Mulholland, W. L. Sjogren, and F. M. Sturms, Jr., "Constants and related Information for Astrodynamic Calculations, 1968," Jet Propulsion Laboratory, TR32-1306, 15 July 1968.

3. Transactions of the International Astronomical Union 10, 72, Moscow, 1960.

4. Comité International des Poids et Mesures, Procès Verbaux des Séances, Deuxième série, 25, 77 (1957).

5. W. Markowitz, R. G. Hall, L. Essen and J. V. L. Parry, Physical Review Letters 1, 105, 1958.

6. Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac, H. M. Stationery Office, London, 1961.

7. International Conference on the Earth-Moon System, B. G. Marsden, A. G. W. Cameron, Editors, Plenum Press, New York 1966.

8. W. H. Munk and G. J. F. MacDonald, The Rotation of the Earth - A Geophysical Discussion, Cambridge University Press, 1960.

9. P. E. Koskela, "Astrodynamic Analysis for the Advanced Orbit/Ephemeris Subsystem," Aeronutronic Division Philco-Ford Corporation, Publication No. U-4180, 1 September 1967.

10. H. T. Hendrickson, "Satellite Control Facility - Computer Program Design Criteria for the Orbit/Ephemeris Subsystem," Aerospace Corporation Report, TOR 469(5110-01)-33, 8 February 1965.

11. C. M. Randall, "Comparison of Sidereal Time Computation in System I and System II," Aerospace Technical Memorandum, ATM-69(4110-01)106,* 27 February 1969.

12. The American Ephemeris and Nautical Almanac for the Year 1968, U.S. Government Printing Office, Washington, D.C., 1966.

13. $\Delta\epsilon$ is tabulated in the Sun Table, pages 18-33, reference 12. $\Delta\epsilon$ is tabulated in -B in the Besselian Day Numbers, pages 260-275 reference 12.

14. P. M. Muller, "Timing Data and Orbit Determination Process at JPL" Space Program Summary No. 37-41, Volume III, page 18, Jet Propulsion Laboratory, 30 September 1966.

15. P. M. Muller, "A Method of Constrained Least-Squares Polynomial Fitting with Application to Analysis of A.1 - WWV from 1955 to 1968," Space Program Summary No. 37-49, Volume II, Page 2[illegible], Jet Propulsion Laboratory, 31 January 1968.

*Not available for distribution outside Aerospace Corporation.

16. U.S. Naval Observatory Time Signals, Bulletins 188 thru 215, 15 May, 1961 to 20 June 1968. U.S. Naval Observatory, Preliminary Times and Coordinates of the Pole, Series 7, No. 1 (January 1968) to No. 79 (3 July 1969).

17. U.S. Naval Observatory Time Signals, Bulletin 215, 20 June 1968, paragraph 13.

APPENDIX A

Comparison of UTC and UT2 as computed from the constants of Table 4 as compared with the US Naval Observatory established scales, which are labelled "EXP".

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 JANUARY 1961 TO 1 AUGUST 1961 07/16/69
A1 + UTC + UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCOIS = 4.01800000E+03
FRQSHF = -1.48958000E-08
UCTAA = 2.43530000E-02
UCTU2C = 2.89090000E-04
UTCU2D = 3.25050000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2437309.5	1.472763	.019873	1.452890	1.472800	.037	1.459700	6.810	10 JAN 61
2437319.5	1.485633	.022681	1.462952	1.485800	.167	1.469300	6.348	20 JAN 61
2437329.5	1.498503	.025490	1.473013	1.498700	.197	1.476900	3.887	30 JAN 61
2437339.5	1.511373	.028298	1.483075	1.511600	.227	1.483400	.325	9 FEB 61
2437349.5	1.524243	.031107	1.493136	1.524500	.257	1.490300	-2.836	19 FEB 61
2437359.5	1.537113	.033915	1.503198	1.537300	.187	1.499300	-3.898	1 MAR 61
2437369.5	1.549983	.036724	1.513259	1.550200	.217	1.510700	-2.559	11 MAR 61
2437379.5	1.562853	.039532	1.523321	1.563100	.247	1.524200	.879	21 MAR 61
2437389.5	1.575723	.042340	1.533382	1.576000	.277	1.536000	2.618	31 MAR 61
2437399.5	1.588593	.045149	1.543444	1.588900	.307	1.544900	1.456	10 APR 61
2437409.5	1.601463	.047957	1.553505	1.601700	.237	1.551700	-1.805	20 APR 61
2437419.5	1.614333	.050766	1.563567	1.614600	.267	1.558300	-5.267	30 APR 61
2437429.5	1.627203	.053574	1.573628	1.627500	.297	1.566300	-7.328	10 MAY 61
2437439.5	1.640073	.056383	1.583690	1.640400	.327	1.576800	-6.890	20 MAY 61
2437449.5	1.652943	.059191	1.593752	1.653200	.257	1.588300	-5.452	30 MAY 61
2437459.5	1.665813	.061999	1.603813	1.666100	.287	1.600500	-3.313	9 JUN 61
2437469.5	1.678683	.064808	1.613875	1.678900	.217	1.612800	-1.075	19 JUN 61
2437479.5	1.691552	.067616	1.623936	1.691700	.148	1.625400	1.464	29 JUN 61
2437489.5	1.704422	.070425	1.633998	1.704500	.078	1.638100	4.102	9 JUL 61
2437499.5	1.717292	.073233	1.644059	1.717300	.008	1.651000	6.941	19 JUL 61
2437509.5	1.730162	.076042	1.654121	1.730200	.038	1.664000	9.879	29 JUL 61

A1U72 37300 COM37512 4018 2.4353E-02 -148.958E-10 +2.8909E-04 +32.505E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 AUGUST 1961 TO 1 JANUARY 1962 07/16/69
A1 # UTC # UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCOIS = 4.23000000E+03
FRQSHF = -1.50000000E-08
UCTAA = 2.80670000E-02
UCTU2C = 2.32910000E-04
UTCU2O = 6.55180000E-10

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2437519.5	1.693092	.014371	1.678721	1.693100	.008	1.677000	-1.721	8 AUG 61
2437529.5	1.706052	.014937	1.691115	1.706000	-.052	1.690000	-1.115	18 AUG 61
2437539.5	1.719012	.015503	1.703509	1.719000	-.012	1.703000	-.509	28 AUG 61
2437549.5	1.731972	.016069	1.715903	1.732100	.128	1.716000	.097	7 SEP 61
2437559.5	1.744932	.016635	1.728297	1.745100	.168	1.728900	.603	17 SEP 61
2437569.5	1.757892	.017201	1.740691	1.758000	.108	1.741600	.909	27 SEP 61
2437579.5	1.770852	.017767	1.753085	1.770900	.048	1.754200	1.115	7 OCT 61
2437589.5	1.783812	.018333	1.765479	1.783800	-.012	1.766600	1.121	17 OCT 61
2437599.5	1.796772	.018899	1.777873	1.796700	-.072	1.779000	1.127	27 OCT 61
2437609.5	1.809732	.019466	1.790266	1.809700	-.032	1.791300	1.034	6 NOV 61
2437619.5	1.822692	.020032	1.802660	1.822600	-.092	1.803500	.840	16 NOV 61
2437629.5	1.835652	.020598	1.815054	1.835600	-.052	1.815500	.446	26 NOV 61
2437639.5	1.848612	.021164	1.827448	1.848600	-.012	1.827300	-.148	6 DEC 61
2437649.5	1.861572	.021730	1.839842	1.861600	.028	1.838700	-1.142	16 DEC 61
2437659.5	1.874532	.022296	1.852236	1.874600	.068	1.849800	-2.436	26 DEC 61

A1UT2 37512 COM37665 4230 2.8067E-02 -150.000E-10 +2.3291E-04 +6.5518E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 JANUARY 1962 TO 1 AUGUST 1963 07/16/69
A1 → UTC → UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCDIS = 4.38300000E+03
FRQSHF = -1.29778000E-08
UCTAA = 3.13700000E-02
UCTU2C = 5.32540000E-04
UTCU2D = -2.12450000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2437669.5	1.886685	.031218	1.855467	1.886900	.215	1.871900	16.433	5 JAN 62
2437679.5	1.897898	.029383	1.868515	1.898100	.202	1.882800	14.285	15 JAN 62
2437689.5	1.909111	.027547	1.881564	1.909300	.189	1.893500	11.936	25 JAN 62
2437699.5	1.920324	.025711	1.894612	1.920500	.176	1.903800	9.188	4 FEB 62
2437709.5	1.931536	.023876	1.907661	1.931700	.164	1.914800	7.139	14 FEB 62
2437719.5	1.942749	.022040	1.920709	1.942900	.151	1.925700	4.991	24 FEB 62
2437729.5	1.953962	.020205	1.933757	1.954100	.138	1.936800	3.043	6 MAR 62
2437739.5	1.965175	.018369	1.946806	1.965400	.225	1.948100	1.294	16 MAR 62
2437749.5	1.976388	.016534	1.959854	1.976700	.312	1.959300	-.554	26 MAR 62
2437759.5	1.987601	.014698	1.972902	1.987900	.299	1.970400	-2.502	5 APR 62
2437769.5	1.998813	.012862	1.985951	1.999200	.387	1.982300	-3.651	15 APR 62
2437779.5	2.010026	.011027	1.998999	2.010400	.374	1.994700	-4.299	25 APR 62
2437789.5	2.021239	.009191	2.012048	2.021600	.361	2.007500	-4.548	5 MAY 62
2437799.5	2.032452	.007356	2.025096	2.032800	.348	2.020900	-4.196	15 MAY 62
2437809.5	2.043665	.005520	2.038144	2.044000	.335	2.033800	-4.344	25 MAY 62
2437819.5	2.054877	.003685	2.051193	2.055200	.323	2.045900	-5.293	4 JUN 62
2437829.5	2.066090	.001849	2.064241	2.066400	.310	2.057200	-7.041	14 JUN 62
2437839.5	2.077303	.000014	2.077290	2.077500	.197	2.068300	-8.990	24 JUN 62
2437849.5	2.088516	-.001822	2.090338	2.088700	.184	2.079600	-10.738	4 JUL 62
2437859.5	2.099729	-.003658	2.103386	2.099900	.171	2.091400	-11.986	14 JUL 62
2437869.5	2.110942	-.005493	2.116435	2.111100	.158	2.104200	-12.235	24 JUL 62
2437879.5	2.122154	-.007329	2.129483	2.122300	.146	2.117700	-11.783	3 AUG 62
2437889.5	2.133367	-.009164	2.142531	2.133500	.133	2.131700	-10.831	13 AUG 62
2437899.5	2.144580	-.011000	2.155580	2.144700	.120	2.146300	-9.280	23 AUG 62
2437909.5	2.155793	-.012835	2.168628	2.155900	.107	2.161700	-6.928	2 SEP 62
2437919.5	2.167006	-.014671	2.181677	2.167100	.094	2.178900	-2.777	12 SEP 62
2437929.5	2.178218	-.016507	2.194725	2.178300	.082	2.195400	.675	22 SEP 62

2437939.5	2.189431	-.018342	2.207773	2.189400	-.031	2.209300	1.527	2 OCT 62
2437949.5	2.200644	-.020178	2.220822	2.200600	-.044	2.222800	1.978	12 OCT 62
2437959.5	2.211857	-.022013	2.233870	2.211900	.043	2.237500	3.630	22 OCT 62
2437969.5	2.223070	-.023849	2.246919	2.223100	.030	2.252400	5.481	1 NOV 62
2437979.5	2.234283	-.025684	2.259967	2.234300	.017	2.266700	6.733	11 NOV 62
2437989.5	2.245495	-.027520	2.273015	2.245500	.005	2.281000	7.985	21 NOV 62
2437999.5	2.256708	-.029356	2.286064	2.256700	-.008	2.295500	9.436	1 DEC 62
2438009.5	2.267721	-.031191	2.299112	2.267900	-.021	2.310500	11.388	11 DEC 62
2438019.5	2.279134	-.033027	2.312161	2.279100	-.034	2.325000	12.839	21 DEC 62
2438029.5	2.290347	-.034862	2.325209	2.290300	-.047	2.338500	13.291	00 JAN 63
2438039.5	2.301559	-.036698	2.338257	2.301500	-.059	2.349100	10.843	10 JAN 63
2438049.5	2.312772	-.038533	2.351306	2.312600	-.172	2.358400	7.094	20 JAN 63
2438059.5	2.323985	-.040369	2.364354	2.323800	-.185	2.367100	2.746	30 JAN 63
2438069.5	2.335198	-.042205	2.377402	2.335000	-.198	2.375500	-1.902	9 FEB 63
2438079.5	2.346411	-.044040	2.390451	2.346200	-.211	2.383900	-6.551	19 FEB 63
2438089.5	2.357624	-.045876	2.403499	2.357400	-.224	2.392400	-11.099	1 MAR 63
2438099.5	2.368836	-.047711	2.416548	2.368700	-.136	2.402500	-14.048	11 MAR 63
2438109.5	2.380049	-.049547	2.429596	2.379900	-.149	2.416500	-13.096	21 MAR 63
2438119.5	2.391262	-.051382	2.442644	2.391200	-.062	2.432100	-10.544	31 MAR 63
2438129.5	2.402475	-.053218	2.455693	2.402400	-.075	2.447500	-0.193	10 APR 63
2438139.5	2.413688	-.055054	2.468741	2.413600	-.088	2.461900	-6.841	20 APR 63
2438149.5	2.424900	-.056889	2.481790	2.424800	-.100	2.475200	-6.590	30 APR 63
2438159.5	2.436113	-.058725	2.494838	2.436100	-.013	2.489500	-5.330	10 MAY 63
2438169.5	2.447326	-.060560	2.507886	2.447300	-.026	2.505400	-2.486	20 MAY 63
2438179.5	2.458539	-.062396	2.520935	2.458600	.061	2.521600	.665	30 MAY 63
2438189.5	2.469752	-.064231	2.533983	2.469800	.048	2.537300	3.317	9 JUN 63
2438199.5	2.480965	-.066067	2.547031	2.481000	.035	2.552700	5.669	19 JUN 63
2438209.5	2.492177	-.067902	2.560080	2.492300	.123	2.567900	7.820	29 JUN 63
2438219.5	2.503390	-.069738	2.573128	2.503500	.110	2.582600	9.472	9 JUL 63
2438229.5	2.514603	-.071574	2.586177	2.514700	.097	2.596900	10.723	19 JUL 63
2438239.5	2.525816	-.073409	2.599225	2.526000	.184	2.611100	11.875	29 JUL 63

AIUT2 37665 COM38242 4383 3.1370E-02 -129.778E-10 +5.3254E-04 -21.245E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 AUGUST 1963 70 1 NOVEMBER 1963 07/16/69
A1 * U7C * U72 7ESTING USING DATU FORMULAS

PARAMETERS

UTCDIS = 4.96000000E+03
FRQSHF = -1.29485000E-08
UC7AA = 4.21570000E-02
UCTU2C = -1.42030000E-03
UTCU2D = -8.55710000E-09

JULIAN DAY	CALC A1-U7C (SEC)	CALC U72-U7C (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DA7E
2438249.5	2.537251	-.090393	2.627645	2.537200	-.051	2.627600	-.045	8 AUG 63
2438259.5	2.548439	-.097787	2.646225	2.548400	-.039	2.645900	-.325	18 AUG 63
2438269.5	2.559626	-.105180	2.664806	2.559500	-.126	2.664700	-.106	28 AUG 63
2438279.5	2.570814	-.112573	2.683387	2.570700	-.114	2.683400	.013	7 SEP 63
2438289.5	2.582001	-.119967	2.701968	2.581900	-.101	2.702100	.132	17 SEP 63
2438299.5	2.593189	-.127360	2.720549	2.593200	.011	2.720700	.151	27 SEP 63
2438309.5	2.604376	-.134753	2.739130	2.604300	-.076	2.739000	-.130	7 OC7 63
2438319.5	2.615564	-.142147	2.757710	2.615500	-.064	2.757600	-.110	17 OC7 63
2438329.5	2.626751	-.149540	2.776291	2.626700	-.051	2.776100	-.191	27 OC7 63
A1U72 38242	COM38334 4960	4.2157E-02	-129.485E-10	-14.203E-04	-85.571E-10	07/16/69		

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A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USND VALUES   07/16/69
 1 NOVEMBER 1963 TO 1 JANUARY 1964                                              07/16/69
   A1 + UTC + UT2  TESTING USING DATU FORMULAS

   PARAMETERS
        UTCDIS =  5.05200000E+03
        FRQSHF = -1.30000000E-08
        UCTAA  =  4.55380000E-02
        UCTU2C = -8.98280000E-04
        UTCU20 = -8.03240000E-09

   JULIAN      CALC       CALC       CALC        EXP                    EXP
    DAY       A1-UTC     UT2-UTC    A1-UT2     A1-UTC   EXP-CALC     A1-UT2   EXP-CALC    DATE
               (SEC)      (SEC)     (SEC)       (SEC)    (MSEC)       (SEC)    (MSEC)

  2438339.5  2.737896   -.057367   2.795263   2.737900     .004     2.794800    -.463    6 NOV 63
  2438349.5  2.749128   -.064307   2.813435   2.749100    -.028     2.813500     .065   16 NOV 63
  2438359.5  2.760360   -.071247   2.831607   2.760300    -.060     2.831900     .293   26 NOV 63
  2438369.5  2.771592   -.078187   2.849779   2.771500    -.092     2.850100     .321    6 DEC 63
  2438379.5  2.782824   -.085127   2.867951   2.782700    -.124     2.867900    -.051   16 DEC 63
  2438389.5  2.794056   -.092067   2.886123   2.793900    -.156     2.885500    -.623   26 DEC 63
A1UT2    38334   COM38395 5052  4.5538E-02 -130.000E-10  -8.9828E-04 -80.324E-10 07/16/69
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A1-UTC AND A1-UT2 CALCULATED FR.M #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 JANUARY 1964 TO 1 APRIL 1964 07/16/69
A1 * UTC * UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTCD15 = 5.11300000E+03
FRQSHF = -1.50000000E-08
UCTAA = 4.66770000E-02
UCTU2C = -1.60840000E-03
UTCU2D = -6.46990000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438399.5	2.805804	-.098740	2.904544	2.805800	-.004	2.903400	-1.144	5 JAN 64
2438409.5	2.818764	-.104330	2.923094	2.818800	.036	2.922900	-.194	15 JAN 64
2438419.5	2.831724	-.109920	2.941644	2.831800	.076	2.9421СJ	.456	25 JAN 64
2438429.5	2.844684	-.115510	2.960194	2.844700	.016	2.961000	.806	4 FEB 64
2438439.5	2.857644	-.121100	2.978744	2.857700	.056	2.979600	.856	14 FEB 64
2438449.5	2.870604	-.126690	2.997294	2.870700	.096	2.997900	.606	24 FEB 64
2438459.5	2.883564	-.132280	3.015844	2.883700	.136	3.016000	.156	5 MAR 64
2438469.5	2.896524	-.137870	3.034394	2.896600	.076	3.034200	-.194	15 MAR 64
2438479.5	2.909484	-.143460	3.052944	2.909600	.116	3.052200	-.744	25 MAR 64

A1UT2 38395 COM38486 5113 4.6677E-02 -150.000E-10 -16.084E-04 -64.699E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM *AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 APRIL 1964 TO 1 SEPTEMBER 1964 07/16/69
A1 - UTC - UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCDIS = 5.20400000E+03
FRQSHF = -1.49768000E-08
UCTAA = 5.03100000E-02
UCTU2C = -7.47240000E-04
UTCU2D = -6.85230000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438489.5	3.022482	-.046611	3.069093	3.022500	.018	3.069400	.307	4 APR 64
2438499.5	3.035422	-.052531	3.087953	3.035500	.078	3.086500	-1.453	14 APR 64
2438509.5	3.048362	-.058451	3.106813	3.048400	.038	3.104300	-2.513	24 APR 64
2438519.5	3.061302	-.064372	3.125674	3.061300	-.002	3.123900	-1.774	4 MAY 64
2438529.5	3.074242	-.070292	3.144534	3.074300	.058	3.144500	-.034	14 MAY 64
2438539.5	3.087182	-.076212	3.163394	3.087200	.018	3.165000	1.606	24 MAY 64
2438549.5	3.100122	-.082133	3.182255	3.100200	.078	3.185100	2.845	3 JUN 64
2438559.5	3.113062	-.088053	3.201115	3.113100	.038	3.204300	3.185	13 JUN 64
2438569.5	3.126002	-.093974	3.219975	3.126000	-.002	3.222800	2.825	23 JUN 64
2438579.5	3.138942	-.099894	3.238836	3.139000	.058	3.240300	1.464	3 JUL 64
2438589.5	3.151882	-.105814	3.257696	3.151900	.018	3.256700	-.996	13 JUL 64
2438599.5	3.164821	-.111735	3.276556	3.164900	.079	3.274300	-2.256	23 JUL 64
2438609.5	3.177761	-.117655	3.295417	3.177800	.039	3.293600	-1.817	2 AUG 64
2438619.5	3.190701	-.123576	3.314277	3.190700	-.001	3.313500	-.777	12 AUG 64
2438629.5	3.203641	-.129496	3.333137	3.203600	-.041	3.333000	-.137	22 AUG 64
2438639.5	3.216581	-.135416	3.351998	3.316600	100.019	3.352400	.402	1 SEP 64

A1UT2 38486 COM38639 5204 5.0310E-02 -149.768E-10 -7.4724E-04 -68.523E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 SEPTEMBER 1964 TO 1 JANUARY 1965 07/16/69
A1 + UTC + UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCDIS = 5.35700000E+03
FRQSHF = -1.50000000E-08
UCTAA = 5.52880000E-02
UCTU2C = -6.49120000E-04
UTCU2D = -8.52600000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438639.5	3.317280	-.038947	3.356227	3.316600	-.680	3.352400	-3.827	1 SEP 64
2438649.5	3.330240	-.046314	3.376554	3.329500	-.740	3.372800	-3.754	11 SEP 64
2438659.5	3.343200	-.053680	3.396880	3.342500	-.700	3.394800	-2.080	21 SEP 64
2438669.5	3.356160	-.061047	3.417207	3.356500	.340	3.416600	-.607	1 OCT 64
2438679.5	3.369120	-.068413	3.437533	3.369400	.280	3.440600	3.067	11 OCT 64
2438689.5	3.382080	-.075780	3.457860	3.382400	.320	3.464400	6.540	21 OCT 64
2438699.5	3.395040	-.083146	3.478186	3.395300	.260	3.483300	5.114	31 OCT 64
2438709.5	3.408000	-.090512	3.498512	3.408300	.300	3.501000	2.488	10 NOV 64
2438719.5	3.420960	-.097879	3.518839	3.421200	.240	3.519400	.561	20 NOV 64
2438729.5	3.433920	-.105245	3.539165	3.434200	.280	3.537700	-1.465	30 NOV 64
2438739.5	3.446880	-.112612	3.559492	3.447100	.220	3.556500	-2.992	10 DEC 64
2438749.5	3.459840	-.119978	3.579818	3.460100	.260	3.577800	-2.018	20 DEC 64
2438759.5	3.472800	-.127345	3.600145	3.473000	.200	3.599700	-.445	30 DEC 64

A1UT2 38639 COM38761 5357 5.5288E-02 -150.000E-10 -6.4912E-04 -85.260E-10 07/16/69

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A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES   07/16/69
 1 JANUARY 1965 TO 1 MARCH 1965                                                 07/16/69
   A1 * UTC * UT2  TESTING USING DATU FORMULAS

   PARAMETERS
        UTCDIS =  5.47900000E+03
        FRQSHF = -1.50000000E-08
        UCTAA  =  5.95930000E-02
        UCTU2C = -4.71610000E-04
        UTCU2D = -7.23210000E-09
```

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438769.5	3.585948	-.033295	3.619243	3.585900	-.048	3.619400	.157	9 JAN 65
2438779.5	3.598908	-.039544	3.638452	3.598900	-.008	3.638100	-.352	19 JAN 65
2438789.5	3.611868	-.045792	3.657660	3.611800	-.068	3.657500	-.160	29 JAN 65
2438799.5	3.624828	-.052041	3.676869	3.624800	-.028	3.677100	.231	8 FEB 65
2438809.5	3.637788	-.058290	3.696078	3.637700	-.088	3.696100	.022	18 FEB 65
2438819.5	3.650748	-.064538	3.715286	3.650700	-.048	3.715100	-.186	28 FEB 65

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A1UT2     38761   COM38820 5479   5.9593E-02 -150.000E-10  -4.7161E-04 -72.321E-10 07/16/69
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A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES   07/16/69
 1 MARCH 1965 TO 1 JULY 1965                                                    07/16/69
   A1 # UTC # UT2  TESTING USING DATU FORMULAS

   PARAMETERS
        UTCDIS =  5.53800000E+03
        FRQSHF = -1.50000000E-08
        UCTAA  =  6.25330000E-02
        UCTU2C =  5.36460000E-04
        UTCU2D = -9.52230000E-09
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JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438829.5	3.763644	.024783	3.738861	3.763700	.056	3.735900	-2.961	10 MAR 65
2438839.5	3.776604	.016556	3.760048	3.776600	-.004	3.758100	-1.948	20 MAR 65
2438849.5	3.789564	.008329	3.781235	3.789600	.036	3.782000	.765	30 MAR 65
2438859.5	3.802524	.000101	3.802423	3.802600	.076	3.807400	4.977	9 APR 65
2438869.5	3.815484	-.008126	3.823610	3.815500	.016	3.827700	4.090	19 APR 65
2438879.5	3.828444	-.016353	3.844797	3.828500	.056	3.845200	.403	29 APR 65
2438889.5	3.841404	-.024581	3.865985	3.841500	.096	3.864700	-1.285	9 MAY 65
2438899.5	3.854364	-.032808	3.887172	3.854400	.036	3.885200	-1.972	19 MAY 65
2438909.5	3.867324	-.041035	3.908359	3.867400	.076	3.906400	-1.959	29 MAY 65
2438919.5	3.880284	-.049262	3.929546	3.880300	.016	3.928200	-1.346	8 JUN 65
2438929.5	3.893244	-.057490	3.950734	3.893300	.056	3.950800	.066	18 JUN 65
2438939.5	3.906204	-.065717	3.971921	3.906200	-.004	3.973600	1.679	28 JUN 65

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A1U72    38820   COM38942 5538  6.2533E-02 -150.000E-10  +5.3646E-04 -95.223E-10 07/16/69
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A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES   07/16/69
 1 JULY 1965 TO 1 SEPTEMBER 1965                                               07/16/69
   A1 + UTC + UT2  TESTING USING DATU FORMULAS

   PARAMETERS
        UTCDIS =  5.66000000E+03
        FRQSHF = -1.50000000E-08
        UCTAA  =  6.68350000E-02
        UCTU2C =  4.88430000E-04
        UTCU2D = -1.18350000E-08
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JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2438949.5	4.019172	.022148	3.997024	4.019200	.028	3.996900	-.124	8 JUL 65
2438959.5	4.032132	.011923	4.020209	4.032200	.068	4.020600	.391	18 JUL 65
2438969.5	4.045092	.001697	4.043395	4.045100	.008	4.043700	.305	28 JUL 65
2438979.5	4.058052	-.008528	4.066580	4.058100	.048	4.066200	-.380	7 AUG 65
2438989.5	4.071012	-.018754	4.089766	4.071000	-.012	4.089200	-.566	17 AUG 65
2438999.5	4.083972	-.028979	4.112951	4.084000	.028	4.113500	.549	27 AUG 65

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A1UT2    38942   CDM39004 5660   6.6835E-02 -150.000E-10   +4.8843E-04 -118.35E-10 07/16/69
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A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 SEPTEMBER 1965 TO 1 JANUARY 1966 07/16/69
A1 * UTC * UT2 TESTING USING DATU FORMULAS

PARAMETERS
UTCDIS = 5.72200000E+03
FRQSHF = -1.50000000E-08
UCTAA = 6.98400000E-02
UCTU2C = 1.00530000E-03
UTCU2D = -1.28910000E-08

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2439009.5	4.196880	.054749	4.142131	4.196900	.020	4.138200	-3.931	6 SEP 65
2439019.5	4.209840	.043611	4.166229	4.209900	.060	4.163200	-3.029	16 SEP 65
2439029.5	4.222800	.032473	4.190327	4.222900	.100	4.188600	-1.727	26 SEP 65
2439039.5	4.235760	.021336	4.214424	4.235800	.040	4.214900	.476	6 OCT 65
2439049.5	4.248720	.010198	4.238522	4.248800	.080	4.240700	2.178	16 OCT 65
2439059.5	4.261680	-.000940	4.262620	4.261700	.020	4.265900	3.280	26 OCT 65
2439069.5	4.274640	-.012078	4.286718	4.274700	.060	4.291200	4.482	5 NOV 65
2439079.5	4.287600	-.023216	4.310816	4.287600	.000	4.315800	4.984	15 NOV 65
2439089.5	4.300560	-.034354	4.334914	4.300600	.040	4.339100	4.186	25 NOV 65
2439099.5	4.313520	-.045491	4.359011	4.313600	.080	4.359900	.889	5 DEC 65
2439109.5	4.326480	-.056629	4.383109	4.326500	.020	4.380000	-3.109	15 DEC 65
2439119.5	4.339440	-.067767	4.407207	4.339500	.060	4.399100	-8.107	25 DEC 65

A1UT2 39004 COM39126 5722 6.9840E-02 -150.000E-10 +10.053E-04 -128.91E-10 07/16/69

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69

1 JANUARY 1966 TO 1 FEBRUARY 1968 07/16/69

A1 , UTC , UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTCDIS = 5.84400000E+03
FRQSHF = -3.00000000E-08
UCTAA = 7.24760000E-02
UCTU2C = -8.91620000E-04
UTCU2D = 2.03980000E-09

JULIAN DAY	CALC A1-UTC (SEC)	CALC UT2-UTC (SEC)	CALC A1-UT2 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-UT2 (SEC)	EXP-CALC (MSEC)	DATE
2439129.5	4.356336	-.052968	4.409304	4.356300	-.036	4.415100	5.796	4 JAN 66
2439139.5	4.382256	-.051206	4.433462	4.382200	-.056	4.438000	4.538	14 JAN 66
2439149.5	4.408176	-.049444	4.457620	4.408100	-.076	4.461200	3.580	24 JAN 66
2439159.5	4.434096	-.047681	4.481777	4.434100	.004	4.485100	3.323	3 FEB 66
2439169.5	4.460016	-.045919	4.505935	4.460000	-.016	4.508500	2.565	13 FEB 66
2439179.5	4.485936	-.044157	4.530093	4.485900	-.036	4.530800	.707	23 FEB 66
2439189.5	4.511856	-.042394	4.554250	4.511800	-.056	4.552400	-1.850	5 MAR 66
2439199.5	4.537776	-.040632	4.578408	4.537700	-.076	4.573000	-5.408	15 MAR 66
2439209.5	4.563696	-.038869	4.602565	4.563600	-.096	4.594300	-8.265	25 MAR 66
2439219.5	4.589616	-.037107	4.626723	4.589600	-.016	4.616100	-10.623	4 APR 66
2439229.5	4.615536	-.035345	4.650881	4.615500	-.036	4.638200	-12.681	14 APR 66
2439239.5	4.641456	-.033582	4.675038	4.641400	-.056	4.661700	-13.338	24 APR 66
2439249.5	4.667376	-.031820	4.699196	4.667300	-.076	4.686100	-13.096	4 MAY 66
2439259.5	4.693296	-.030057	4.723353	4.693200	-.096	4.710800	-12.553	14 MAY 66
2439269.5	4.719216	-.028295	4.747511	4.719200	-.016	4.736400	-11.111	24 MAY 66
2439279.5	4.745136	-.026533	4.771669	4.745100	-.036	4.761900	-9.769	3 JUN 66
2439289.5	4.771056	-.024770	4.795826	4.771000	-.056	4.787200	-8.626	13 JUN 66
2439299.5	4.796976	-.023008	4.819984	4.796900	-.076	4.812000	-7.984	23 JUN 66
2439309.5	4.822896	-.021246	4.844142	4.822900	.004	4.836600	-7.542	3 JUL 66
2439319.5	4.848816	-.019483	4.868299	4.848800	-.016	4.861300	-6.999	13 JUL 66
2439329.5	4.874736	-.017721	4.892457	4.874700	-.036	4.885700	-6.757	23 JUL 66
2439339.5	4.900656	-.015958	4.916614	4.900600	-.056	4.910000	-6.614	2 AUG 66
2439349.5	4.926576	-.014196	4.940772	4.926600	.024	4.935100	-5.672	12 AUG 66
2439359.5	4.952496	-.012434	4.964930	4.952500	.004	4.961100	-3.830	22 AUG 66
2439369.5	4.978416	-.010671	4.989087	4.978400	-.016	4.987800	-1.287	01 SEP 66
2439379.5	5.004336	-.008909	5.013245	5.004300	-.036	5.015000	1.755	11 SEP 66
2439389.5	5.030255	-.007146	5.037402	5.030200	-.056	5.042300	4.898	21 SEP 66

2439399.5	5.056176	-.005384	5.061560	5.056200	.024	5.070000	8.440	1 OCT 66
2439409.5	5.062096	-.003622	5.085718	5.082100	.004	5.097600	11.882	11 OCT 66
2439419.5	5.108016	-.001859	5.109875	5.108000	-.016	5.124900	15.025	21 OCT 66
2439429.5	5.133936	-.000097	5.134033	5.133900	-.036	5.151900	17.867	31 OCT 66
2439439.5	5.159856	.001666	5.158190	5.159900	.044	5.178400	20.210	10 NOV 66
2439449.5	5.185776	.003428	5.182348	5.185600	.024	5.203900	21.552	20 NOV 66
2439459.5	5.211696	.005190	5.206506	5.211700	.004	5.228100	21.594	30 NOV 66
2439469.5	5.237616	.006953	5.230663	5.236900	-.716	5.251200	20.537	10 DEC 66
2439479.5	5.263536	.008715	5.254821	5.262800	-.736	5.272800	17.979	20 DEC 66
2439489.5	5.289456	.010477	5.278979	5.288600	-.856	5.292500	13.521	30 DEC 66
2439499.5	5.315376	.012240	5.303136	5.314600	-.776	5.310900	7.764	9 JAN 67
2439509.5	5.341296	.014002	5.327294	5.340500	-.796	5.331900	4.606	19 JAN 67
2439519.5	5.367216	.015765	5.351451	5.366400	-.816	5.354700	3.249	29 JAN 67
2439529.5	5.393136	.017527	5.375609	5.392300	-.836	5.378400	2.791	08 FEB 67
2439539.5	5.419056	.019289	5.399767	5.418200	-.856	5.402300	2.533	18 FEB 67
2439549.5	5.444976	.021052	5.423924	5.444100	-.876	5.425900	1.976	28 FEB 67
2439559.5	5.470896	.022814	5.448082	5.470100	-.796	5.448800	.718	10 MAR 67
2439569.5	5.496816	.024577	5.472239	5.496000	-.816	5.471300	-.939	20 MAR 67
2439579.5	5.522736	.026339	5.496397	5.521900	-.836	5.495000	-1.397	30 MAR 67
2439589.5	5.548656	.028101	5.520555	5.547800	-.856	5.519700	-.855	09 APR 67
2439599.5	5.574576	.029864	5.544712	5.573700	-.876	5.544700	-.012	19 APR 67
2439609.5	5.600496	.031626	5.568870	5.599700	-.796	5.569700	.830	29 APR 67
2439619.5	5.626416	.033388	5.593028	5.625600	-.816	5.594600	1.572	09 MAY 67
2439629.5	5.652336	.035151	5.617185	5.651500	-.836	5.619300	2.115	19 MAY 67
2439639.5	5.678256	.036913	5.641343	5.677400	-.856	5.642900	1.557	29 MAY 67
2439649.5	5.704176	.038676	5.665500	5.703300	-.876	5.665300	-.200	08 JUN 67
2439659.5	5.730096	.040438	5.689658	5.729300	-.796	5.686800	-2.858	18 JUN 67
2439669.5	5.756016	.042200	5.713816	5.755200	-.816	5.708200	-5.616	28 JUN 67
2439679.5	5.781936	.043963	5.737973	5.781100	-.836	5.730300	-7.673	08 JUL 67
2439689.5	5.807856	.045725	5.762131	5.807000	-.856	5.753700	-8.431	18 JUL 67
2439699.5	5.833776	.047488	5.786288	5.832900	-.876	5.777800	-8.488	28 JUL 67
2439709.5	5.859696	.049250	5.810446	5.858900	-.796	5.802700	-7.746	07 AUG 67
2439719.5	5.885616	.051012	5.834604	5.884800	-.816	5.827600	-7.004	17 AUG 67
2439729.5	5.911536	.052775	5.858761	5.910700	-.836	5.852400	-6.361	27 AUG 67
2439739.5	5.937456	.054537	5.882919	5.936600	-.856	5.877100	-5.819	06 SEP 67
2439749.5	5.963376	.056300	5.907076	5.962500	-.876	5.901100	-5.976	16 SEP 67
2439759.5	5.989296	.058062	5.931234	5.988500	-.796	5.924600	-6.634	26 SEP 67
2439769.5	6.015216	.059824	5.955392	6.014400	-.816	5.948000	-7.392	06 OCT 67
2439779.5	6.041136	.061587	5.979549	6.040300	-.836	5.972700	-6.849	16 OCT 67
2439789.5	6.067056	.063349	6.003707	6.066200	-.856	5.999400	-4.307	26 OCT 67
2439799.5	6.092976	.065111	6.027865	6.092100	-.876	6.026200	-1.665	05 NOV 67
2439809.5	6.118896	.066874	6.052022	6.118000	-.896	6.052300	.278	15 NOV 67

2439819.5	6.144816	.068636	6.076180	6.144000	-.816	6.076900	.720	25 NOV 67
2439829.5	6.170736	.070399	6.100337	6.169900	-.836	6.098100	-2.237	05 DEC 67
2439839.5	6.196656	.072161	6.124495	6.195800	-.856	6.121200	-3.295	15 DEC 67
2439849.5	6.222576	.073923	6.148653	6.221700	-.876	6.144300	-4.353	25 DEC 67
2439858.5	6.245904	.075510	6.170394	6.245400	-.504	6.171400	1.006	03 JAN 68
2439865.5	6.264048	.076743	6.187305	6.263400	-.648	6.187400	.095	10 JAN 68
2439872.5	6.282192	.077977	6.204215	6.281400	-.792	6.203400	-.815	17 JAN 68
2439879.5	6.300336	.079211	6.221125	6.299400	-.936	6.220400	-.725	24 JAN 68
2439886.5	6.318480	.080444	6.238035	6.317400	-1.080	6.237400	-.636	31 JAN 68

A1UT2 39126 COM39887 5644 7.2476E-02 -300.000E-10 -8.9162E-04 +20.398E-10 07/16/69

A1-UTC AND A1-U72 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69
1 FEBRUARY 1968 TO 12 FEBRUARY 1969 07/16/69
A1 # U7C # U72 TESTING USING DATU FORMULAS

PARAMETERS

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U7COIS =  6.60500000E+03
FRQSHF = -3.00000000E-08
UC7AA  =  1.03665000E-01
UCTU2C = -1.12200000E-04
U7CU20 =  9.11130000E-10
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JULIAN DAY	CALC A1-U7C (SEC)	CALC UT2-U7C (SEC)	CALC A1-U72 (SEC)	EXP A1-UTC (SEC)	EXP-CALC (MSEC)	EXP A1-U72 (SEC)	EXP-CALC (MSEC)	DATE
2439893.5	6.235452	-.006260	6.241712	6.235400	-.052	6.253400	11.688	07 FEB 68
2439900.5	6.253596	-.005709	6.259305	6.254400	.804	6.270400	11.095	14 FEB 68
2439907.5	6.271740	-.005158	6.276898	6.272400	.660	6.289400	12.502	21 FEB 68
2439914.5	6.289884	-.004607	6.294491	6.290210	.326	6.306400	11.909	28 FEB 68
2439921.5	6.308028	-.004055	6.312083	6.308350	.322	6.321400	9.317	6 MAR 68
2439928.5	6.326172	-.003504	6.329676	6.326490	.318	6.337400	7.724	13 MAR 68
2439935.5	6.344316	-.002953	6.347269	6.344640	.324	6.353400	6.131	20 MAR 68
2439942.5	6.362460	-.002402	6.364862	6.362780	.320	6.370400	5.538	27 MAR 68
2439949.5	6.380604	-.001851	6.382455	6.380930	.326	6.386400	3.945	03 APR 68
2439956.5	6.398748	-.001300	6.400048	6.399070	.322	6.400400	.352	10 APR 68
2439963.5	6.416892	-.000749	6.417641	6.417210	.318	6.413400	-4.241	17 APR 68
2439970.5	6.435036	-.000198	6.435234	6.435360	.324	6.427400	-7.834	24 APR 68
2439977.5	6.453180	.000353	6.452827	6.453500	.320	6.444400	-8.427	01 MAY 68
2439984.5	6.471324	.000904	6.470420	6.471650	.326	6.462400	-8.020	08 MAY 68
2439991.5	6.489468	.001455	6.488013	6.489790	.322	6.481400	-6.613	15 MAY 68
2439998.5	6.507612	.002006	6.505606	6.507930	.318	6.502400	-3.206	22 MAY 68
2440005.5	6.525756	.002557	6.523199	6.526080	.324	6.520400	-2.799	29 MAY 68
2440012.5	6.543900	.003108	6.540792	6.544220	.320	6.537400	-3.392	05 JUN 68
2440019.5	6.562044	.003659	6.558385	6.562370	.326	6.554400	-3.985	12 JUN 68
2440026.5	6.580188	.004210	6.575978	6.580510	.322	6.573400	-2.578	19 JUN 68
2440033.5	6.598332	.004761	6.593571	6.598650	.318	6.590400	-3.171	26 JUN 68
2440040.5	6.616476	.005312	6.611164	6.616800	.324	6.606400	-4.764	03 JUL 68
2440047.5	6.634620	.005863	6.628757	6.634940	.320	6.621400	-7.357	10 JUL 68
2440054.5	6.652764	.006415	6.646349	6.653090	.326	6.637400	-8.949	17 JUL 68
2440061.5	6.670908	.006966	6.663942	6.671230	.322	6.654400	-9.542	24 JUL 68
2440068.5	6.689052	.007517	6.681535	6.689370	.318	6.672400	-9.135	31 JUL 68
2440075.5	6.707196	.008068	6.699128	6.707520	.324	6.689400	-9.728	07 AUG 68

2440082.5	6.725340	.008619	6.716721	6.725660	.320	6.705400	-11.321	14 AUG 68
2440089.5	6.743484	.009170	6.734314	6.743810	.326	6.723400	-10.914	21 AUG 68
2440096.5	6.761628	.009721	6.751907	6.761950	.322	6.744400	-7.507	28 AUG 68
2440103.5	6.779772	.010272	6.769500	6.780090	.318	6.765400	-4.100	04 SEP 68
2440110.5	6.797916	.010823	6.787093	6.798240	.324	6.787400	.307	11 SEP 68
2440117.5	6.816060	.011374	6.804686	6.816380	.320	6.811400	6.714	18 SEP 68
2440124.5	6.834204	.011925	6.822279	6.834530	.326	6.834400	12.121	25 SEP 68
2440131.5	6.852348	.012476	6.839872	6.852670	.322	6.855400	15.528	02 OCT 68
2440138.5	6.870492	.013027	6.857465	6.870810	.318	6.873400	15.935	09 OCT 68
2440145.5	6.888636	.013578	6.875058	6.888960	.324	6.891400	16.342	16 OCT 68
2440152.5	6.906780	.014129	6.892651	6.907100	.320	6.906400	13.749	23 OCT 68
2440159.5	6.924924	.014680	6.910244	6.925250	.326	6.922400	12.156	30 OCT 68
2440166.5	6.943068	.015231	6.927837	6.943390	.322	6.939400	11.563	06 NOV 68
2440173.5	6.961212	.015782	6.945430	6.961530	.318	6.957400	11.970	13 NOV 68
2440180.5	6.979356	.016333	6.963023	6.979680	.324	6.976400	13.377	20 NOV 68
2440187.5	6.997500	.016884	6.980616	6.997820	.320	6.993400	12.784	27 NOV 68
2440194.5	7.015644	.017436	6.998208	7.015970	.326	7.010400	12.192	04 DEC 68
2440201.5	7.033788	.017987	7.015801	7.034110	.322	7.026400	10.599	11 DEC 68
2440208.5	7.051932	.018538	7.033394	7.052250	.318	7.041400	8.006	18 DEC 68
2440215.5	7.070076	.019089	7.050987	7.070400	.324	7.056400	5.413	25 DEC 68
2440222.5	7.088220	.019640	7.068580	7.088540	.320	7.057400	-11.180	01 JAN 69
2440229.5	7.106364	.020191	7.086173	7.106690	.326	7.071400	-14.773	08 JAN 69
2440236.5	7.124508	.020742	7.103766	7.124830	.322	7.086400	-17.366	15 JAN 69
2440243.5	7.142652	.021293	7.121359	7.142970	.318	7.103400	-17.959	22 JAN 69
2440250.5	7.160796	.021844	7.138952	7.161120	.324	7.120400	-18.552	29 JAN 69
2440257.5	7.178940	.022395	7.156545	7.179260	.320	7.139400	-17.145	05 FEB 69
2440264.5	7.197084	.022946	7.174138	7.197410	.326	7.157400	-16.738	12 FEB 69
2440271.5	7.215228	.023497	7.191731	7.215550	.322	7.176400	-15.331	19 FEB 69
2440278.5	7.233372	.024048	7.209324	7.233690	.318	7.195400	-13.924	26 FEB 69
2440285.5	7.251516	.024599	7.226917	7.251840	.324	7.213400	-13.517	05 MAR 69
2440292.5	7.269660	.025150	7.244510	7.269980	.320	7.232400	-12.110	12 MAR 69
2440299.5	7.287804	.025701	7.262103	7.288130	.326	7.250400	-11.703	19 MAR 69
2440306.5	7.305948	.026252	7.279696	7.306270	.322	7.269400	-10.296	26 MAR 69
2440313.5	7.324092	.026803	7.297289	7.324410	.318	7.289400	-7.889	02 APR 69
2440320.5	7.342236	.027354	7.314882	7.342560	.324	7.308400	-6.482	09 APR 69
2440334.5	7.378524	.028457	7.350067	7.378850	.326	7.349400	-.667	23 APR 69
2440341.5	7.396668	.029008	7.367660	7.396990	.322	7.372400	4.740	30 APR 69
2440348.5	7.414812	.029559	7.385253	7.415130	.318	7.393400	8.147	07 MAY 69
2440355.5	7.432956	.030110	7.402846	7.433280	.324	7.412400	9.554	14 MAY 69
2440362.5	7.451100	.030661	7.420439	7.451420	.320	7.430400	9.961	21 MAY 69
2440369.5	7.469244	.031212	7.438032	7.469570	.326	7.446400	8.368	28 MAY 69
2440376.5	7.487388	.031763	7.455625	7.487710	.322	7.463400	7.775	04 JUN 69

APPENDIX B

Comparison of seasonal correction S = UT2 - UT1 as obtained from the parameters of Table 5 with the correction established by the US Naval Observatory and indicated by "EXP".

1961 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.210E-02*SIN(ARG) +-1.690E-02*COS(ARG) +-6.900E-03*SIN(2*ARG) + 5.900E-03*COS(2*ARG)

RMS DEVIATION = 2.54993E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2437309.5	9	-.01000	-.00977	-.2269	10 JAN 61
2437319.5	19	-.00800	-.00842	.4223	20 JAN 61
2437329.5	29	-.00700	-.00687	-.1344	30 JAN 61
2437339.5	39	-.00500	-.00488	-.1216	9 FEB 61
2437349.5	49	-.00200	-.00228	.2754	19 FEB 61
2437359.5	59	.00100	.00106	-.0552	1 MAR 61
2437369.5	69	.00500	.00513	-.1263	11 MAR 61
2437379.5	79	.01000	.00984	.1614	21 MAR 61
2437389.5	89	.01500	.01498	.0193	31 MAR 61
2437399.5	99	.02000	.02024	-.2444	10 APR 61
2437409.5	109	.02500	.02525	-.2517	20 APR 61
2437419.5	119	.03000	.02959	.4079	30 APR 61
2437429.5	129	.03300	.03287	.1341	10 MAY 61
2437439.5	139	.03500	.03473	.2730	20 MAY 61
2437449.5	149	.03500	.03492	.0766	30 MAY 61
2437459.5	159	.03300	.03333	-.3268	9 JUN 61
2437469.5	169	.03000	.02995	.0486	19 JUN 61
2437479.5	179	.02500	.02496	.0431	29 JUN 61
2437489.5	189	.01900	.01864	.3629	9 JUL 61
2437499.5	199	.01100	.01139	-.3938	19 JUL 61
2437509.5	209	.00400	.00370	.3000	29 JUL 61
2437519.5	219	-.00400	-.00394	-.0550	8 AUG 61
2437529.5	229	-.01100	-.01106	.0414	18 AUG 61
2437539.5	239	-.01700	-.01723	.2337	28 AUG 61
2437549.5	249	-.02200	-.02215	.1464	7 SEP 61
2437559.5	259	-.02600	-.02561	-.3908	17 SEP 61
2437569.5	269	-.02800	-.02757	-.4318	27 SEP 61
2437579.5	279	-.02800	-.02810	.1012	7 OCT 61
2437589.5	289	-.02700	-.02740	.3999	17 OCT 61
2437599.5	299	-.02600	-.02574	-.2599	27 OCT 61
2437609.5	309	-.02300	-.02344	.4433	6 NOV 61
2437619.5	319	-.02100	-.02084	-.1648	16 NOV 61
2437629.5	329	-.01800	-.01821	.2065	26 NOV 61
2437639.5	339	-.01600	-.01578	-.2215	6 DEC 61
2437649.5	349	-.01400	-.01368	-.3198	16 DEC 61
2437659.5	359	-.01200	-.01194	-.0625	26 DEC 61

1962 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.100E-02*SIN(ARG) +-1.350E-02*COS(ARG) +-7.400E-03*SIN(2*ARG) + 6.700E-03*COS(2*ARG)

RMS DEVIATION = 1.46891E-03

JULIAN DAY	TIME FROM REF DAY	U72-U71 (EXP) SEC	U72-U71 (CALC) SEC	EXP-CALC MSEC	DATE
2437669.5	4	-.01000	-.00640	-3.5973	5 JAN 62
2437679.5	14	-.00900	-.00559	-3.4080	15 JAN 62
2437689.5	24	-.00800	-.00484	-3.1637	25 JAN 62
2437699.5	34	-.00600	-.00386	-2.1407	4 FEB 62
2437709.5	44	-.00400	-.00240	-1.5998	14 FEB 62
2437719.5	54	-.00100	-.00026	-.7440	24 FEB 62
2437729.5	64	.00300	.00268	.3155	6 MAR 62
2437739.5	74	.00700	.00642	.5837	16 MAR 62
2437749.5	84	.01200	.01081	1.1909	26 MAR 62
2437759.5	94	.01600	.01561	.3867	5 APR 62
2437769.5	104	.02000	.02048	-.4817	15 APR 62
2437779.5	114	.02400	.02500	-1.0036	25 APR 62
2437789.5	124	.02700	.02875	-1.7482	5 MAY 62
2437799.5	134	.03000	.03131	-1.3124	15 MAY 62
2437809.5	144	.03000	.03237	-2.3666	25 MAY 62
2437819.5	154	.03000	.03169	-1.6947	4 JUN 62
2437829.5	164	.02800	.02922	-1.2216	14 JUN 62
2437839.5	174	.02400	.02503	-1.0270	24 JUN 62
2437849.5	184	.01800	.01934	-1.3421	4 JUL 62
2437859.5	194	.01200	.01253	-.5301	14 JUL 62
2437869.5	204	.00400	.00505	-1.0526	24 JUL 62
2437879.5	214	-.00300	-.00257	-.4256	3 AUG 62
2437889.5	224	-.01000	-.00983	-.1696	13 AUG 62
2437899.5	234	-.01700	-.01624	-.7593	23 AUG 62
2437909.5	244	-.02200	-.02142	-.5797	2 SEP 62
2437919.5	254	-.02600	-.02511	-.8912	12 SEP 62
2437929.5	264	-.02800	-.02719	-.8094	22 SEP 62
2437939.5	274	-.02900	-.02770	-1.3014	2 OCT 62
2437949.5	284	-.02800	-.02680	-1.1972	12 OCT 62
2437959.5	294	-.02600	-.02478	-1.2165	22 OCT 62
2437969.5	304	-.02300	-.02199	-1.0074	1 NOV 62
2437979.5	314	-.02000	-.01881	-1.1900	11 NOV 62
2437989.5	324	-.01600	-.01560	-.4034	21 NOV 62
2437999.5	334	-.01300	-.01265	-.3470	1 DEC 62
2438009.5	344	-.01000	-.01019	.1861	11 DEC 62
2438019.5	354	-.00700	-.00829	1.2891	21 DEC 62
2438029.5	364	-.00500	-.00694	1.9365	00 JAN 63

1963 SEASONAL VARIATION CORRECTION 04/08/69.
PROJECTION AND COMPARISON OF CALCULATED VALUES
CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)
RMS DEVIATION = 3.15795E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2438039.5	9	-.00400	-.00359	-.4053	10 JAN 63
2438049.5	19	-.00200	-.00233	.3325	20 JAN 63
2438059.5	29	-.00100	-.00117	.1740	30 JAN 63
2438069.5	39	-0.	.00012	-.1210	9 FEB 63
2438079.5	49	.00200	.00178	.2230	19 FEB 63
2438089.5	59	.00400	.00396	.0351	1 MAR 63
2438099.5	69	.00700	.00677	.2285	11 MAR 63
2438109.5	79	.01000	.01018	-.1792	21 MAR 63
2438119.5	89	.01400	.01406	-.0586	31 MAR 63
2438129.5	99	.01800	.01818	-.1760	10 APR 63
2438139.5	109	.02200	.02221	-.2140	20 APR 63
2438149.5	119	.02600	.02580	.1958	30 APR 63
2438159.5	129	.02900	.02857	.4332	10 MAY 63
2438169.5	139	.03000	.03015	-.1583	20 MAY 63
2438179.5	149	.03000	.03029	-.2927	30 MAY 63
2438189.5	159	.02900	.02882	.1836	9 JUN 63
24381 9.5	169	.02600	.02569	.3083	19 JUN 63
2438209.5	179	.02100	.02103	-.0272	29 JUN 63
2438219.5	189	.01500	.01507	-.0687	9 JUL 63
2438229.5	199	.00800	.00818	-.1788	19 JUL 63
2438239.5	209	.00100	.00080	.1952	29 JUL 63
2438249.5	219	-.00700	-.00656	-.4368	8 AUG 63
2438259.5	229	-.01400	-.01344	-.5609	18 AUG 63
2438269.5	239	-.02000	-.01939	-.6142	28 AUG 63
2438279.5	249	-.02400	-.02406	.0564	7 SEP 63
2438289.5	259	-.02800	-.02722	-.7759	17 SEP 63
2438299.5	269	-.02900	-.02880	-.2006	27 SEP 63
2438309.5	279	-.02900	-.02883	-.1680	7 OCT 63
2438319.5	289	-.02700	-.02750	.4987	17 OCT 63
2438329.5	299	-.02500	-.02508	.0766	27 OCT 63
2438339.5	309	-.02200	-.02191	-.0922	6 NOV 63
2438349.5	319	-.01800	-.01836	.3568	16 NOV 63
2438359.5	329	-.01500	-.01477	-.2313	26 NOV 63
2438369.5	339	-.01100	-.01143	.4302	6 DEC 63
2438379.5	349	-.00800	-.00858	.5407	16 DEC 63
2438389.5	359	-.00600	-.00619	.1938	26 DEC 63

1964 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 3.02754E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2438399.5	4	-.00400	-.00433	.3346	5 JAN 64
2438409.5	14	-.00300	-.00294	-.0639	15 JAN 64
2438419.5	24	-.00200	-.00176	-.2448	25 JAN 64
2438429.5	34	-.00100	-.00056	-.4416	4 FEB 64
2438439.5	44	.00100	.00089	.1085	14 FEB 64
2438449.5	54	.00300	.00280	.2033	24 FEB 64
2438459.5	64	.00500	.00529	-.2893	5 MAR 64
2438469.5	74	.00800	.00841	-.4057	15 MAR 64
2438479.5	84	.01200	.01207	-.0723	25 MAR 64
2438489.5	94	.01600	.01611	-.1057	4 APR 64
2438499.5	104	.02000	.02023	-.2272	14 APR 64
2438509.5	114	.02400	.02409	-.0891	24 APR 64
2438519.5	124	.02700	.02731	-.3120	4 MAY 64
2438529.5	134	.03000	.02953	.4732	14 MAY 64
2438539.5	144	.03000	.03042	-.4179	24 MAY 64
2438549.5	154	.03000	.02976	.2382	3 JUN 64
2438559.5	164	.02800	.02746	.5434	13 JUN 64
2438569.5	174	.02400	.02354	.4604	23 JUN 64
2438579.5	184	.01800	.01819	-.1895	3 JUL 64
2438589.5	194	.01200	.01171	.2862	13 JUL 64
2438599.5	204	.00500	.00452	.4778	23 JUL 64
2438609.5	214	-.00300	-.00291	-.0890	2 AUG 64
2438619.5	224	-.01000	-.01009	.0917	12 AUG 64
2438629.5	234	-.01600	-.01655	.5528	22 AUG 64
2438639.5	244	-.02200	-.02190	-.1021	1 SEP 64
2438649.5	254	-.02600	-.02584	-.1629	11 SEP 64
2438659.5	264	-.02800	-.02821	.2109	21 SEP 64
2438669.5	274	-.02900	-.02900	.0002	1 OCT 64
2438679.5	284	-.02800	-.02832	.3207	11 OCT 64
2438689.5	294	-.02600	-.02640	.4034	21 OCT 64
2438699.5	304	-.02400	-.02356	-.4372	31 OCT 64
2438709.5	314	-.02000	-.02016	.1576	10 NOV 64
2438719.5	324	-.01700	-.01655	-.4523	20 NOV 64
2438729.5	334	-.01300	-.01305	.0534	30 NOV 64
2438739.5	344	-.01000	-.00992	-.0791	10 DEC 64
2438749.5	354	-.00700	-.00730	.2979	20 DEC 64
2438759.5	364	-.00500	-.00522	.2231	30 DEC 64

1965 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 2.94839E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2438769.5	8	-.00400	-.00374	-.2646	9 JAN 65
2438779.5	18	-.00200	-.00245	.4501	19 JAN 65
2438789.5	28	-.00100	-.00129	.2920	29 JAN 65
2438799.5	38	-0.	-.00002	.0213	8 FEB 65
2438809.5	48	.00200	.00159	.4103	18 FEB 65
2438819.5	58	.00400	.00372	.2811	28 FEB 65
2438829.5	68	.00600	.00646	-.4626	10 MAR 65
2438839.5	78	.01000	.00981	.1858	20 MAR 65
2438849.5	88	.01400	.01366	.3447	30 MAR 65
2438859.5	98	.01800	.01776	.2380	9 APR 65
2438869.5	108	.02200	.02182	.1759	19 APR 65
2438879.5	118	.02600	.02548	.5237	29 APR 65
2438889.5	128	.02800	.02834	-.3382	9 MAY 65
2438899.5	138	.03000	.03006	-.0570	19 MAY 65
2438909.5	148	.03000	.03035	-.3498	29 MAY 65
2438919.5	158	.02900	.02904	-.0387	8 JUN 65
2438929.5	168	.02600	.02608	-.0763	18 JUN 65
2438939.5	178	.02200	.02156	.4430	28 JUN 65
2438949.5	188	.01600	.01571	.2868	8 JUL 65
2438959.5	198	.00900	.00890	.1025	18 JUL 65
2438969.5	208	.00100	.00155	-.5502	28 JUL 65
2438979.5	218	-.00600	-.00584	-.1592	7 AUG 65
2438989.5	228	-.01300	-.01279	-.2133	17 AUG 65
2438999.5	238	-.01900	-.01884	-.1563	27 AUG 65
2439009.5	248	-.02400	-.02365	-.3457	6 SEP 65
2439019.5	258	-.02700	-.02698	-.0213	16 SEP 65
2439029.5	268	-.02900	-.02871	-.2869	26 SEP 65
2439039.5	278	-.02900	-.02889	-.1060	6 OCT 65
2439049.5	288	-.02800	-.02769	-.3138	16 OCT 65
2439059.5	298	-.02500	-.02536	.3584	26 OCT 65
2439069.5	308	-.02200	-.02225	.2479	5 NOV 65
2439079.5	318	-.01900	-.01872	-.2811	15 NOV 65
2439089.5	328	-.01500	-.01512	.1204	25 NOV 65
2439099.5	338	-.01200	-.01175	-.2536	5 DEC 65
2439109.5	348	-.00900	-.00881	-.1941	15 DEC 65
2439119.5	358	-.00600	-.00640	.4037	25 DEC 65

1966 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 3.19140E-04

JULIAN DAY	TIME FROM REF DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2439129.5	3	-.00500	-.00449	-.5057	4 JAN 66
2439139.5	13	-.00300	-.00306	.0625	14 JAN 66
2439149.5	23	-.00200	-.00187	-.1300	24 JAN 66
2439159.5	33	-.00100	-.00069	-.3143	3 FEB 66
2439169.5	43	.00100	.00073	.2710	13 FEB 66
2439179.5	53	.00300	.00258	.4187	23 FEB 66
2439189.5	63	.00500	.00501	-.0118	5 MAR 66
2439199.5	73	.00800	.00807	-.0672	15 MAR 66
2439209.5	83	.01200	.01169	.3148	25 MAR 66
2439219.5	93	.01600	.01569	.3068	4 APR 66
2439229.5	103	.02000	.01982	.1794	14 APR 66
2439239.5	113	.02400	.02373	.2747	24 APR 66
2439249.5	123	.02700	.02703	-.0292	4 MAY 66
2439259.5	133	.02900	.02936	-.3602	14 MAY 66
2439269.5	143	.03000	.03040	-.3956	24 MAY 66
2439279.5	153	.03000	.02990	.0990	3 JUN 66
2439289.5	163	.02800	.02776	.2386	13 JUN 66
2439299.5	173	.02400	.02400	.0002	23 JUN 66
2439309.5	183	.01900	.01878	.2189	3 JUL 66
2439319.5	193	.01200	.01240	-.4009	13 JUL 66
2439329.5	203	.00500	.00526	-.2603	23 JUL 66
2439339.5	213	-.00200	-.00217	.1709	2 AUG 66
2439349.5	223	-.00900	-.00940	.3987	12 AUG 66
2439359.5	233	-.01600	-.01595	-.0489	22 AUG 66
2439369.5	243	-.02100	-.02142	.4228	01 SEP 66
2439379.5	253	-.02500	-.02551	.5120	11 SEP 66
2439389.5	263	-.02800	-.02805	.0456	21 SEP 66
2439399.5	273	-.02900	-.02899	-.0098	1 OCT 66
2439409.5	283	-.02800	-.02845	.4490	11 OCT 66
2439419.5	293	-.02700	-.02664	-.3576	21 OCT 66
2439429.5	303	-.02400	-.02388	-.1216	31 OCT 66
2439439.5	313	-.02100	-.02051	-.4869	10 NOV 66
2439449.5	323	-.01700	-.01691	-.0917	20 NOV 66
2439459.5	333	-.01400	-.01339	-.6101	30 NOV 66
2439469.5	343	-.01000	-.01021	.2128	10 DEC 66
2439479.5	353	-.00800	-.00754	-.4647	20 DEC 66
2439489.5	363	-.00600	-.00541	-.5930	30 DEC 66

1967 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 2.90073E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2439499.5	8	-.00400	-.00374	-.2646	9 JAN 67
2439509.5	18	-.00200	-.00245	.4501	19 JAN 67
2439519.5	28	-.00100	-.00129	.2920	29 JAN 67
2439529.5	38	0.	-.00002	.0213	08 FEB 67
2439539.5	48	.00200	.00159	.4103	18 FEB 67
2439549.5	58	.00400	.00372	.2811	28 FEB 67
2439559.5	68	.00600	.00646	-.4626	10 MAR 67
2439569.5	78	.01000	.00981	.1858	20 MAR 67
2439579.5	88	.01400	.01366	.3447	30 MAR 67
2439589.5	98	.01800	.01776	.2380	09 APR 67
2439599.5	108	.02200	.02182	.1759	19 APR 67
2439609.5	118	.02600	.02548	.5237	29 APR 67
2439619.5	128	.02800	.02834	-.3382	09 MAY 67
2439629.5	138	.03000	.03006	-.0570	19 MAY 67
2439639.5	148	.03000	.03035	-.3498	29 MAY 67
2439649.5	158	.02900	.02904	-.0387	08 JUN 67
2439659.5	168	.02600	.02608	-.0763	18 JUN 67
2439669.5	178	.02200	.02156	.4430	28 JUN 67
2439679.5	188	.01600	.01571	.2868	08 JUL 67
2439689.5	198	.00900	.00890	.1025	18 JUL 67
2439699.5	208	.00200	.00155	.4498	28 JUL 67
2439709.5	218	-.00600	-.00584	-.1592	07 AUG 67
2439719.5	228	-.01300	-.01279	-.2133	17 AUG 67
2439729.5	238	-.01900	-.01884	-.1563	27 AUG 67
2439739.5	248	-.02400	-.02365	-.3457	06 SEP 67
2439749.5	258	-.02700	-.02698	-.0213	16 SEP 67
2439759.5	268	-.02900	-.02871	-.2869	26 SEP 67
2439769.5	278	-.02900	-.02889	-.1060	06 OCT 67
2439779.5	288	-.02800	-.02769	-.3138	16 OCT 67
2439789.5	298	-.02500	-.02536	.3584	26 OCT 67
2439799.5	308	-.02200	-.02225	.2479	05 NOV 67
2439809.5	318	-.01900	-.01872	-.2811	15 NOV 67
2439819.5	328	-.01500	-.01512	.1204	25 NOV 67
2439829.5	338	-.01200	-.01175	-.2536	05 DEC 67
2439839.5	348	-.00900	-.00881	-.1941	15 DEC 67
2439849.5	358	-.00660	-.00640	.4037	25 DEC 67

1968 SEASONAL VARIATION CORRECTION 04/08/69.

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 4.27421E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2439858.5	2	-.00500	-.00466	-.3416	03 JAN 68
2439865.5	9	-.00300	-.00359	.5947	10 JAN 68
2439872.5	16	-.00300	-.00269	-.3104	17 JAN 68
2439879.5	23	-.00200	-.00187	-.1300	24 JAN 68
2439886.5	30	-.00200	-.00105	-.9454	31 JAN 68
2439893.5	37	-0.	-.00016	.1602	07 FEB 68
2439900.5	44	-0.	.00089	-.8915	14 FEB 68
2439907.5	51	.00200	.00217	-.1679	21 FEB 68
2439914.5	58	.00300	.00372	-.7189	28 FEB 68
2439921.5	65	.00600	.00557	.4268	6 MAR 68
2439928.5	72	.00700	.00773	-.7344	13 MAR 68
2439935.5	79	.01000	.01018	-.1792	20 MAR 68
2439942.5	86	.01200	.01286	-.8573	27 MAR 68
2439949.5	93	.01600	.01569	.3068	03 APR 68
2439956.5	100	.01900	.01859	.4109	10 APR 68
2439963.5	107	.02200	.02143	.5700	17 APR 68
2439970.5	114	.02400	.02409	-.0891	24 APR 68
2439977.5	121	.02600	.02643	-.4348	01 MAY 68
2439984.5	128	.02800	.02834	-.3382	08 MAY 68
2439991.5	135	.03000	.02968	.3200	15 MAY 68
2439998.5	142	.03000	.03036	-.3579	22 MAY 68
2440005.5	149	.03100	.03029	.7073	29 MAY 68
2440012.5	156	.03000	.02943	.5665	05 JUN 68
2440019.5	163	.02800	.02776	.2386	12 JUN 68
2440026.5	170	.02500	.02529	-.2915	19 JUN 68
2440033.5	177	.02200	.02207	-.0734	26 JUN 68
2440040.5	184	.01800	.01819	-.1895	03 JUL 68
2440047.5	191	.01400	.01375	.2481	10 JUL 68
2440054.5	198	.00900	.00890	.1025	17 JUL 68
2440061.5	205	.00400	.00378	.2184	24 JUL 68
2440068.5	212	-.00100	-.00143	.4288	31 JUL 68
2440075.5	219	-.00700	-.00656	-.4368	07 AUG 68
2440082.5	226	-.01100	-.01146	.4554	14 AUG 68
2440089.5	233	-.01600	-.01595	-.0489	21 AUG 68

2440096.5	240	-.02000	-.01992	-.0850	28 AUG 68
2440103.5	247	-.02300	-.02324	.2372	04 SEP 68
2440110.5	254	-.02600	-.02584	-.1629	11 SEP 68
2440117.5	261	-.02700	-.02767	.6670	18 SEP 68
2440124.5	268	-.02800	-.02871	.7131	25 SEP 68
2440131.5	275	-.02900	-.02900	-.0047	02 OCT 68
2440138.5	282	-.02800	-.02856	.5645	09 OCT 68
2440145.5	289	-.02800	-.02750	-.5013	16 OCT 68
2440152.5	296	-.02600	-.02590	-.1019	23 OCT 68
2440159.5	303	-.02400	-.02388	-.1216	30 OCT 68
2440166.5	310	-.02200	-.02156	-.4361	06 NOV 68
2440173.5	317	-.01900	-.01908	.0804	13 NOV 68
2440180.5	324	-.01700	-.01655	-.4523	20 NOV 68
2440187.5	331	-.01400	-.01407	.0732	27 NOV 68
2440194.5	338	-.01200	-.01175	-.2536	04 DEC 68
2440201.5	345	-.01000	-.00963	-.3658	11 DEC 68
2440208.5	352	-.00800	-.00778	-.2217	18 DEC 68
2440215.5	359	-.00600	-.00619	.1938	25 DEC 68

1969 SEASONAL VARIATION CORRECTION 07/15/69

PROJECTION AND COMPARISON OF CALCULATED VALUES

CALC = 2.200E-02*SIN(ARG) +-1.200E-02*COS(ARG) +-5.900E-03*SIN(2*ARG) + 7.000E-03*COS(2*ARG)

RMS DEVIATION = 3.80692E-04

JULIAN DAY	TIME FROM BEG DAY	UT2-UT1 (EXP) SEC	UT2-UT1 (CALC) SEC	EXP-CALC MSEC	DATE
2440222.5	0	-.00500	-.00500	-.0000	01 JAN 69
2440229.5	7	-.00300	-.00388	.8796	08 JAN 69
2440236.5	14	-.00300	-.00294	-.0639	15 JAN 69
2440243.5	21	-.00200	-.00210	.1001	22 JAN 69
2440250.5	28	-.00100	-.00129	.2920	29 JAN 69
2440257.5	35	-.00100	-.00043	-.5715	05 FEB 69
2440264.5	42	-0.00000	.00057	-.5708	12 FEB 69
2440271.5	49	.00100	.00178	-.7770	19 FEB 69
2440278.5	56	.00300	.00325	-.2456	26 FEB 69
2440285.5	63	.00500	.00501	-.0118	05 MAR 69
2440292.5	70	.00700	.00709	-.0865	12 MAR 69
2440299.5	77	.01000	.00945	.5458	19 MAR 69
2440306.5	84	.01200	.01207	-.0723	26 MAR 69
2440313.5	91	.01500	.01487	.1279	02 APR 69
2440320.5	98	.01800	.01776	.2380	09 APR 69
2440334.5	112	.02400	.02336	.6444	23 APR 69
2440341.5	119	.02600	.02580	.1958	30 APR 69
2440348.5	126	.02800	.02785	.1533	07 MAY 69
2440355.5	133	.02900	.02936	-.3602	14 MAY 69
2440362.5	140	.03000	.03024	-.2370	21 MAY 69
2440369.5	147	.03100	.03039	.6093	28 MAY 69
2440378.5	154	.03000	.02976	.2382	04 JUN 69
2440383.5	161	.02800	.02832	-.3219	11 JUN 69
2440390.5	168	.02600	.02608	-.0763	18 JUN 69
2440397.5	175	.02300	.02306	-.0650	25 JUN 69
2440404.5	182	.01900	.01936	-.3611	02 JUL 69
2440411.5	189	.01500	.01507	-.0687	09 JUL 69

UT2UT1 40222COM 40586 0.0220 -0.0120 -0.0059 0.0070 07/15/69

APPENDIX C

Time conversion constant update procedure.

All of the parameters required to convert from A1 to UTC, from UTC to UT2 and from UT2 to UT1 are included in a constant block (CBLK) called 'AUBLK in the AOES System II Data Base. The constants for the first two conversions are contained in Table 'AUTAB within this block. The correlation between the symbols used in this report and the item names in this table are indicated by the headings in Table 4. 'AUTAB has space for a maximum of 10 entries. Table 4 already has 14 entries so not all of Table 4 can be used as 'AUTAB. Because of the way 'AUTAB is employed by the computer routine 'DATU, the entries must occur in consecutive order with no omissions. Thus to support currently flying missions the last ten entries in Table 4 would be used.

New entries must be made in 'AUTAB whenever a step change is made in UTC or whenever the frequency offset is changed. It may be advantageous to make additional entries when it is impossible to fit UTC to UT2 within the required accuracy over the time period between UTC changes with a single set of constanta. In the eight year period covered by Table 4 this has been necesaary only once, namely the entry of 1 August 1963.

In addition to adding new entries to 'AUTAB the values in the last (most recent) entry should reflect as large an amount of data as is available on the relation between UTC, UT2. The most convenient source of this information is the "Preliminary Times and Coordinates of the Pole. Series 7" published by the US Naval Observatory. The method by which this information is incorporated in the baae involves tradeoffs between frequent changes in the data base, level of management authority which should permit changes in the data base, auxiliary computer programs required, etc., all considerations outside the scope of this report. We suggest one scheme simply to indicate the type of procedure which might be used.

This updating procedure is outline aa a flow chart in Fig. C-1. The criteria for making a change in 'AUTAB is that for some input day there is a greater than 30 msec difference between UT2 as calculated from the constants in 'AUTAB and UT2 as obtained from the Naval Observatory. If a change ia necessary the first attempt is to change the constanta relating UTC to UT2 to better values. If elimination of the troublesome time difference ia not possible this way then a new entry should be made in 'AUTAB.

A new entry is made in 'AUTAB whenever the $|UT2_{cal}-UT2_{USNO}|$ ia too large or whenever a UTC discontinuity occurs. For either cause the new entry is always the last one in the table and if one must be dropped to keep within the table size it must be the first entry in the table. The items in the new entry are determined as shown in Table C-1. When a new entry is made there will be no further need to update the old last entry. Therefore the best values of UCTU2C and UCTU2D for that time period should be inserted even if the old values were giving acceptable answers.

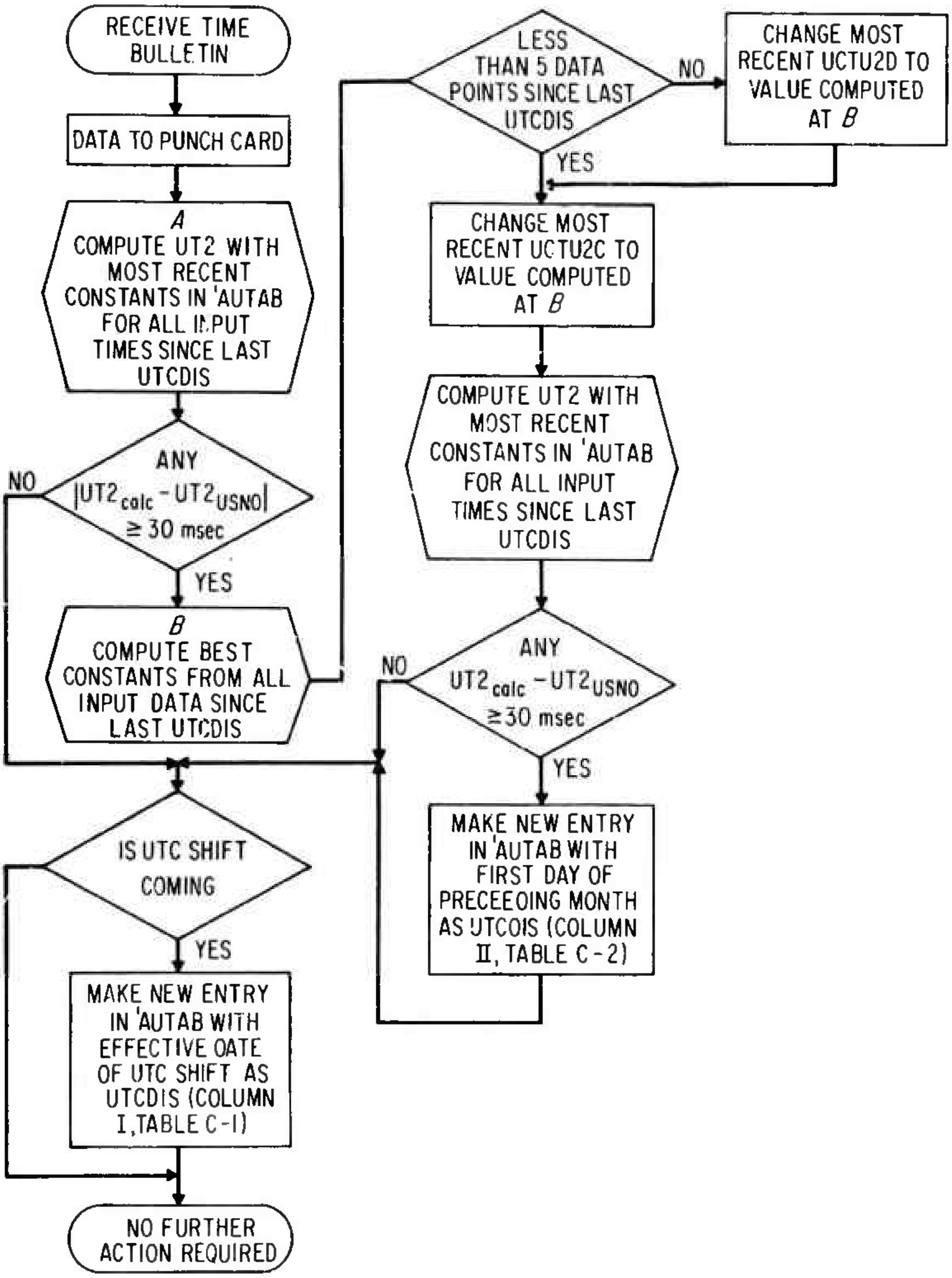

Figure C-1. Flow Chart of a Possible Procedure for Updating 'AUTAB.

Table C-1. Source for Values of Items in New Entry in 'AUTAB

ITEM	I New entry because of change in UTC constants	II New entry because $\lvert UT2_{calc} - UT2_{USNO} \rvert$ has grown too large
Next to last entry in 'AUTAB (last entry before the new entry)		
UTCDIS	Unchanged from old last entry	Unchanged from old last entry
FRQSHF	Unchanged from old last entry	Unchanged from old last entry
UCTAA	Unchanged from old last entry	Unchanged from old last entry
UCTU2C	Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry.	Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry.
UCTU2D	Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry.	Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry.
New last entry in 'AUTAB		
UTCDIS	Effective date of change in days from AOES base time.	First day of month preceding date when $UT2_{calc} - UT2_{USNO}$ first exceeded 30 msec, measured in days from AOES base time.
FRQSHF	As defined by USNO for new period	Same as FRQSHF in preceding entry
UCTAA	$A1-UTC_{USNO}$ at UTCDIS as determined by interpolation in USNO time bulletins	$A1-UTC_{USNO}$ at UTCDIS as determined by interpolation in USNO time bulleting
UCTU2C	UCTU2C of preceding entry ± step change announced for UTC	Calculated from least squares fit to data since last discontinuity.
UCTU2D	Same as UCTU2D in preceding entry	Calculated from least squares fit to data since last discontinuity.

APPENDIX D

Summary of Constant Block AUBLK Data Valuea.

Name	Description	Value or Source
AUTAI	UTC to A1 and A1 to UTC Conversion	Table 4 and Appendix C
UTCIND	Internal Flag	
A1IND	Internal Flag	
U1K1	Seasonal Variation Constants	Table 5
U1K2		
U1K3		
U1K4		
THK1	Conatant for Sidereal Time Comp.	0.2779876155 Eq. 2
THK2	Constant for Sidereal Time Comp.	$0.2737909294 \times 10^{-2}$ Eq. 2
THDK1	Sidereal Rate Conatant	1.002737909294 Eq. 2

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13 ABSTRACT

The time transformations and time dependent inputs for spstial transformations in the Advanced Orbit/Ephemeris Subsystem (AOES) presently being implemented by the Air Force Satellite Control Facility have been reviewed. The principle results are:

1. The relations described in the Milestone 2 documents describing the computer routines include sll relations required to satisfy the accuracy design goals of AOES.

2. If future systems require higher accuracy the present time-related transformations will not be adequate. The improvements must involve the following:

   s. Wander of the pole of rotation with respect to the crust of the earth can no longer be ignored.

   b. The empirical relations betwee earth rotation time scales (UT2, UT1) and stomic time scales (A1, UTC, etc.) must be improved, probably by fitting over shorter periods of time.

   c. Nutstion terms of smplitude less than 0.2 src second must be included.

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Atomic Time Universal Time Time Transformations

Abstract (Continued)

3. A best set of constants to be employed by the AOES relating UT2 to UTC for the period 1 January 1961 to 30 June 1969 have been calculated. A procedure is suggested for the continuous review of the applicability of these and subsequent constsnts, with provisions for updating them as required.

4. Values for comparison with computer routine results are presented for many of the quantities under study.

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